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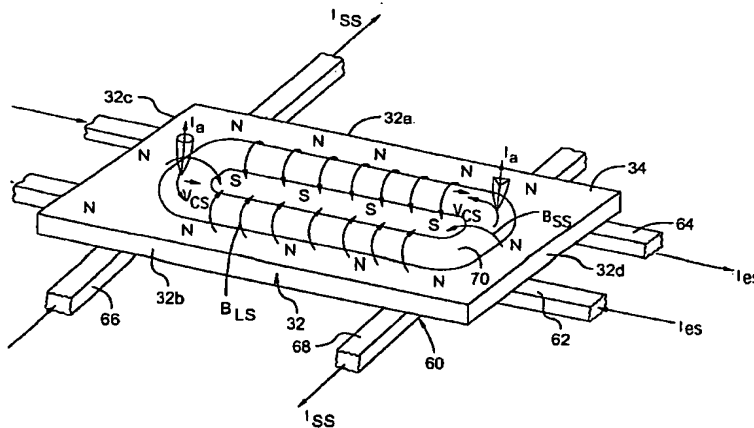
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**(54) Title:** RECTANGULAR FILTERED VAPOR PLASMA SOURCE AND METHOD OF CONTROLLING VAPOR PLASMA FLOW



**(57) Abstract:** The invention provides an arc coating apparatus having a steering magnetic field source comprising steering conductors (62, 64, 66, 68) disposed along the short sides (32c, 32d) of a rectangular target (32) behind the target, and a magnetic focusing system disposed along the long sides (32a, 32b) of the target (32) in front of the target which confines the flow of plasma between magnetic fields generated on opposite long sides (32a, 32b) of the target (32). The plasma focusing system can be used to deflect the plasma flow off of the working axis of the cathode. Each steering conductor (62, 64, 66, 68) can be controlled independently. In a further embodiment, electrically independent steering conductors (62, 64, 66, 68) are disposed along opposite long sides (32a, 32b) of the cathode plate (32), and by selectively varying a current through one conductor, the path of the arc spot shifts to widen the erosion corridor. The invention also provides a plurality of internal anodes, and optionally a surrounding anode for deflecting the plasma flow.

**WO 2005/040451 A1**

WO 2005/040451 A1



— with amended claims

*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

WO 2005/040451

PCT/US2004/030603

1

RECTANGULAR FILTERED VAPOR PLASMA SOURCE AND METHOD OF  
CONTROLLING VAPOR PLASMA FLOW

Field of Invention

This invention relates to apparatus for the production of coatings in a vacuum. In particular, this invention relates to a vacuum arc coating apparatus having a rectangular filtered cathodic or magnetron arc source providing improved arc spot scanning, and a plasma focusing and filtering system.

Background of the Invention

Many types of vacuum arc coating apparatus utilize a cathodic arc source in which an electric arc is formed between an anode and a cathode plate in a vacuum chamber. The arc generates a cathode spot on a target surface of the cathode, which evaporates the cathode material into the chamber. The cathodic evaporate disperses as a plasma within the chamber, and upon contact with one or more substrates coats the substrates with the cathode material, which may be metal, ceramic etc. An example of such an arc coating apparatus is described in U.S. Patent No. 3,793,179 issued February 19, 1974 to Sablev, which is incorporated herein by reference.

An arc coating apparatus of this type is advantageous for use in the coating of large substrates and multiple substrates, due to the large surface area of the cathode which can be evaporated into a large volume coating chamber. However, in a large surface area cathode arc coating apparatus of this type a significant portion of the target evaporation surface of the cathode plate goes largely unused, due to the scanning pattern of arc spots which follows certain physical principles:

1. The arc discharge tends to move in a direction which reduces the voltage drop in the arc circuit, and the arc spot thus tends to migrate to regions on the target surface which are closest to the anodic current conductor. Where multiple current conductors traverse the cathode the arc spot will occasionally migrate into the region between conductors where it may remain for a considerable time because no

WO 2005/040451

PCT/US2004/030603

2

steering mechanism is present to move the arc spot back to the desired evaporation zone.

2. In the case of metal cathodes the arc spot follows a retrograde motion according to the "anti-ampere force" principle, and is thus attracted to the coaxial magnetic force lines generated by the anodic current conductor.

3. In the case of a cathode formed from a material which does not have a melting phase, for example a sintered or graphite cathode, the arc spot moves according to the "ampere force" principle and is repelled from the coaxial magnetic force lines generated by the anodic current conductor.

4. The arc spot is attracted to the region where the tangential component of a transverse magnetic field is strongest.

5. The arc spot tends to migrate away from the apex of an acute angle at the point of intersection between a magnetic field line and the cathode target surface (the "acute angle" rule).

These effects result in a limited erosion zone relative to the available area of the target surface of the cathode plate, reducing the life of the cathode and dispersing cathodic evaporate into the coating chamber in non-uniform concentrations.

In a large area cathode arc coating apparatus using a metal cathode plate the anti-ampere motion of the arc spot and the tendency of the arc to seek the lowest voltage drop combine to largely confine the arc spot to the vicinity of the anodic conductor, substantially limiting the erosion zone to the region of the target surface surrounding the anodic conductor. This results in a very small area inside the coating chamber in which the cathodic evaporate is concentrated enough to apply a uniform coating to the substrates. However, it is not possible to construct the cathode plate so that the desired coating material is located only in the erosion zone, since the arc spot will occasionally stray out of the erosion zone and if the target surface is not entirely composed of the selected coating material the cathodic evaporate from outside the desired erosion zone will contaminate the coating on the substrates.

WO 2005/040451

PCT/US2004/030603

3

In the case of a cathode plate formed from a material which does not have a melting phase, the tendency of the arc spot to move in an ampere direction, away from the region of the anodic conductor, is opposed by the tendency of the arc discharge to settle toward the region of lowest voltage drop. In these cases the arc spot tends to move chaotically over the target surface of the cathode and the cathodic evaporate accordingly disperses in random locations and non-uniform concentrations within the coating chamber, rendering uniform coating of the substrates improbable. This random motion also causes the arc spot to move off of the target surface of the cathode and causes undesirable erosion of non-target portions of the cathode plate, for example the side edges.

U.S. Patent No. 4,448,659 issued May 15, 1984 to Morrison, which is incorporated herein by reference, describes an arc coating apparatus providing a cathode in the form of a plate with a large target surface for creating cathodic evaporate. A confinement ring composed of a magnetically permeable material surrounds the cathode to confine the arc spot to the target surface. Such plasma sources can be used for the production of coatings on large and long articles, but present the following disadvantages:

1. Despite the initial low probability of the presence of cathodic spots on the protective ring, over time the cathodic evaporate coats the ring and cathodic spots are produced on the ring with increasing frequency. This results in contamination of the coating by the ring material, and ultimately in ring failure.

2. In self-steering cathodic arc sources it is not possible to use external magnetic fields in the vicinity of the target surface of the cathode. It is therefore not possible in such an apparatus to use a plasma-focusing magnetic field, as the influence of the focusing magnetic field makes the distribution of cathodic spots on the working surface of the cathode irregular and non-uniform. Any external magnetic field, for example for focusing or deflecting the arc plasma flow, interferes with the self-sustained magnetic field generated by the cathode and anode current conductors and disrupts the self-steering character of the cathode spot. However, the absence of magnetic focusing reduces the efficiency of the coating process and

WO 2005/040451

PCT/US2004/030603

4

impairs the quality of substrate coatings, because the content of the neutral component (macroparticles, clusters and neutral atoms) in the region of the substrates, and thus in the substrate coating, increases.

3. A cathode in this type of plasma source rapidly becomes  
5 concave due to evaporative decomposition, and its useful life is therefore relatively short. Moreover, since the evaporation surface of the cathode becomes concave in a relatively short time it is practically impossible to use a high voltage pulse spark igniter in such a design, so that a mechanical igniter must be used which lowers working reliability and stability.

10 4. While the confinement ring prevents the arc spot from straying off of the target surface, it does not affect the tendency of the arc spot to migrate toward the anodic conductor in the case of metal cathodes, or to move chaotically over the target surface in the case of non-metal cathodes.

Accordingly, self-steering arc plasma sources tend to use the target  
15 surface inefficiently and the cathode thus has a relatively short useful life.

The erosion efficiency of the target surface can be improved by providing an arc spot steering system to steer the arc spot along a selected path about the target surface. This increases the size of the region within the coating chamber in which coating can occur.

20 For example, the scanning pattern of a cathode spot can be controlled by providing a closed-loop magnetic field source disposed beneath the target surface of the cathode, in a manner similar to that described in U.S. Patent No. 4,724,058 issued February 9, 1988 to Morrison, which is incorporated herein by reference. The magnetic field source establishes a magnetic field in a selected direction over the  
25 target surface, which directs the cathode spot in a direction substantially perpendicular to the direction of the magnetic field and thus provides more efficient evaporation of the target surface. This approach is based on the principle of arc spot motion whereby an arc spot is attracted to the region where the tangential component of a transverse magnetic field is strongest.

WO 2005/040451

PCT/US2004/030603

5

However, this still significantly limits the area of the target surface of the cathode which is available for erosion, because this type of arc coating apparatus creates a stagnation zone in the region where the tangential component of the magnetic field is strongest. The cathode spot eventually settles in the stagnation zone, tracing a retrograde path about the erosion zone and creating a narrow erosion corridor on the target surface. This limits the uniformity of the coating on the substrates and reduces the working life of the cathode.

U.S. patent No. 5,997,705 issued December 7, 1999 to Welty, which is incorporated herein by reference, teaches a rectangular cathode plate in which the evaporation surface is located on the peripheral edge of the cathode plate, the arc spot being confined to the evaporation surface by cathode shields disposed over opposed faces of the cathode plate. Deflecting electrodes disposed about the cathode plate direct the plasma stream in two directions, parallel to the faces of the cathode plate.

In this apparatus the substrates must surround the edges of the cathode plate, and the cathode plate occupies most of the space within the apparatus. Thus, in order to coat a significant number of substrates the cathode plate, and thus the apparatus itself, must be extremely large. Also, filtration in this apparatus is poor, since the substrates are directly exposed to droplets and macroparticles entrained in the cathodic evaporate.

A deflecting electrode is described in U.S. Patent No. 5,840,163 issued November 24, 1998 to Welty, which is incorporated herein by reference. This patent teaches a rectangular vacuum arc plasma source in which a deflecting electrode is mounted inside the plasma duct and either electrically floating or biased positively with respect to the anode. However, this device requires a sensor which switches the polarity of the magnetic field when the arc spot on the rectangular source has reached the end of the cathode, in order to move the arc spot to the other side of the cathode. This results in an undesirable period where the magnetic field is zero; the arc is therefore not continuous, and is not controlled during this period. Consequently this 'pseudo-random' steering method cannot consistently produce reliable or reproducible coatings.

WO 2005/040451

PCT/US2004/030603

6

U.S. Patent No. 4,673,477 to Ramalingam proposes that the magnetic field source can be moved to shift the magnetic field lines and increase the utilization efficiency of the target surface. However, the mechanical adaptations required for such a system make the apparatus too complicated and expensive to be practical.

5           Where an external magnetic field is present the arc spot follows the "acute angle" rule, according to which the arc spot tends to migrate away from the apex of an acute angle at the point of intersection between a magnetic field line and the cathode target surface. The basic principle is that a cathodic spot formed by a vacuum arc in a fairly strong magnetic field (in the order of 100 Gauss), the force lines  
10 of which cross the surface of the cathode at an acute angle, will move in a reverse (retrograde) direction perpendicular to the tangential component of the field and, concurrently, displace away from the apex of the angle (for example, see Cathodic Processes of Electric Arc by Kesaev I.G., Nauka, 1968). This results in the arc spot settling beneath the apex of the arch-shaped portion of the magnetic field which  
15 projects over the target surface.

U.S. Patent No. 5,587,207 issued December 24, 1996 to Gorokhovskiy, which is incorporated herein by reference, teaches that cathode spot confinement under a closed loop-type linear anode can be enhanced by a conductor which encases the anode to form a closed loop magnetic coil, with the magnetic field lines oriented  
20 in the direction shown in Figures 29 and 30 therein. Simultaneous use of both the closed-loop magnetic steering coil behind the cathode and a closed-loop linear anode in front of the target evaporation surface (with or without an enclosed magnetic coil) results in a synergistic improvement of arc discharge stability and thus cathode spot motion. The anode can be configured in any desired pattern, the configuration thereof  
25 being limited only by the periphery of the target surface. The arc spot will scan the target surface under the influence of the transverse magnetic field (in an ampere direction in the case of cathodes of carbon and related sintered materials or in an anti-ampere direction in the case of metal cathodes), virtually unaffected by the current flowing through the anodic conductor.

WO 2005/040451

PCT/US2004/030603

7

A disadvantage of this approach is that the arc spot will occasionally migrate from the selected erosion zone to another part of the cathode target surface where the intensity of the transverse magnetic field is small and, there being no means available to return the arc spot to the desired erosion zone, will stagnate in the low magnetic field region. In the case of a carbon-based cathode plate, when the velocity of arc spot movement is low enough the arc spot can settle in any stagnation zone where the transverse magnetic field is close to zero, and will not return to the erosion zone.

U.S. Patent No. 5,435,900 issued July 25, 1995 to Gorokhovskiy, which is incorporated herein by reference, discloses a deflecting magnetic system surrounding a parallelepipedal plasma guide, in which the deflecting conductors force the plasma toward the substrate holder. However, this patent does not address the problem of magnetically steering an arc spot around a rectangular cathode plate in the presence of a deflecting magnetic field.

In case of conventional rectangular magnetron sputtering sources the magnetron plasma discharge is confined near the target surface by a closed loop magnetron magnetic field. This creates a closed loop shape of the discharge located along the magnetic corridor defined between outer and central magnetic poles where the magnetic field is strongest. In this conventional design the magnetic field is balanced between the outer and central poles. This design has the drawback of low target utilization rate and inefficient energy consumption (P. Robinson and A. Matthews, Characteristics of a Dual Purpose Cathodic Arc /Magnetron Sputtering System, Surface and Coating Technology, 43/44 (1990) 288-298, which is incorporated herein by reference). This can be also used for a dual purpose arc/magnetron vapor plasma deposition source. If the cathode target is equipped with a magnetron high voltage low current power supply and a separate low voltage high current arc power supply as well as an arc igniter, it is possible to run the target in both magnetron sputtering and arc evaporation modes. This was successfully demonstrated by running large rectangular arc/magnetron cathode targets (P. Robinson and A. Matthews, Characteristics of a Dual Purpose Cathodic Arc /Magnetron Sputtering System, Surface and Coating Technology, 43/44 (1990) 288-

WO 2005/040451

PCT/US2004/030603

8

298). The setback of this approach is an extremely low utilization rate of the target when it is running in arc mode due to cathodic arc spots having a tendency to settle or stay in a location near the area where the tangential component of the arch-shape planar magnetron-type magnetic field is strongest.

5                   These designs also suffer from a low ionization rate of the plasma vapor flow due to a high degree of confinement provided by the balance magnetron magnetic field. In an unbalanced magnetron magnetic system design the central pole can be weakening or removed, providing that much higher ion fluxes can be extracted from near the target magnetron discharge zone (B. Window and N. Savvides, Journal  
10 Vacuum Science and Technology A, 4 (1986) p.196, which is incorporated herein by reference). U.S. Patent No. 5,160,595 to Hauzer, which was issued in November 3, 1992, which is incorporated herein by reference, describes an arc/magnetron apparatus in which an edge magnet arrangement is displaceable in an axial direction relative to a preferably fixedly mounted center pole permanent magnet so that a cathode sputtering  
15 process and/or an arc discharge process can be realized depending on the relative position of the edge magnet arrangement and the center pole magnet. When the edge magnets are removed the central pole magnet can provide a steering magnetic field for steering arc spots in arc evaporation mode. This design allows for better utilization of cathode target material, but still suffers from a relatively small arc steering area. It  
20 also confines most of the ionized plasma flow on or near the target surface, which significantly reduces the ionization rate of vapor plasma flux and results in reduced coating adhesion.

US Patent No. 6,730,196 to Wang, which was issued in May 4, 2004, which is incorporated herein by reference, teaches that a magnetic focusing coil  
25 disposed in a processing area between the magnetron target and substrates to be coated can extract additional plasma flow from near the target area to yield higher ionization of the magnetron sputtering plasma flux. The magnetic field of this focusing coil overlaps the magnetron magnetic field, e.g. the direction of magnetic force lines of the magnetic field created by the focusing coil is aligned with the  
30 direction of magnetic force lines created between edge poles and central poles of the magnetron magnets. One disadvantage of this design is that the focusing coil is not

WO 2005/040451

PCT/US2004/030603

9

adapted to the shape of the magnetron target. This will result in a high non-uniformity of magnetron plasma flow when applied to rectangular magnetron targets.

Neither of the above mentioned magnetron and arc/magnetron sputtering source designs allow for the elimination of macroparticles from the magnetron plasma flow. These macroparticles are generated on the face surface of the magnetron target as a result of micro-arcing processes. This results in an increase of coating defects, which is especially detrimental for such a precision applications as metal interconnect copper, and magnetic media coatings and other semiconductor and optical coatings. It also reduces the functional properties of hard wear-resistant coatings for cutting tools, increases the coefficient of friction in coatings designated for low friction applications, and decreases the corrosion resistance of both decorative and protective coatings.

WO 2005/040451

PCT/US2004/030603

10

Summary of the Invention

The present invention overcomes these disadvantages by providing a steering magnetic field source comprising a plurality of electrically independent closed-loop steering conductors disposed in the vicinity of the target surface. In the preferred embodiment each steering conductor can be controlled independently of the other steering conductors.

The steering conductors may be disposed in front of or behind the target surface of the cathode plate. When disposed in front of the target surface the steering magnetic field lines intersect with the target surface at an obtuse angle, which obviates the motion-limiting effect of the acute angle principle and allows the arc spot to move over a larger region of the target surface, thereby further increasing the size of the erosion zone.

Steering conductors disposed in front of the target surface can also serve as focusing conductors, which confine the plasma and direct it toward the substrates. In these embodiments opposed steering/focusing conductors disposed along the long sides of the cathode plate generate magnetic cusps which create a magnetic pathway within which the plasma flows toward the substrates. Additional focusing conductors may be disposed along the plasma duct downstream, preferably with magnetic fields that overlap within the plasma duct to create a continuous magnetic wall along the plasma duct.

Increasing the current through one steering conductor increases the strength of the magnetic field generated by that conductor relative to the strength of the magnetic field of the steering conductor along the opposite side of the cathode plate, shifting the magnetic field on the opposite side of the cathode plate transversely. Selective unbalancing of the steering conductor currents can thus compensate for the magnetic influence of the focusing conductors, and if desired can increase the effective breadth of the erosion zone to thus provide more uniform erosion of the target surface and a larger area within the coating chamber in which the cathodic evaporate is dispersed at concentrations sufficient to uniformly coat the substrates.

WO 2005/040451

PCT/US2004/030603

11

In a further embodiment, groups of steering conductors are disposed along opposite sides of the cathode plate. By selectively applying a current through one conductor in each group, the path of the arc spot shifts to an erosion corridor defined by the active steering conductor.

5           The present invention further provides means for restricting the cathode spot from migrating into selected regions of the target evaporation surface outside of the desired erosion zone. The invention accomplishes this by providing a shield at floating potential positioned over one or more the selected regions of the target evaporation surface, which prevents the arc spot from forming in or moving  
10 into the shielded region. In one preferred embodiment the shield is positioned immediately above the region of the target surface in the vicinity of the anode, spaced from the target surface. The evaporation zone is thus restricted to the area of the target surface surrounding the shield, protecting the anode from deposition of cathodic evaporate and providing better distribution of cathodic evaporate over the substrates to  
15 be coated, which results in more uniform coatings over a greater coating area.

The shield can be used to keep arc spots away from any region where the negative conductor traverses the cathode, which represents the lowest voltage drop relative to the anode. Where a large anode or multiple anodes are provided the shield restrains the arc spot from migrating into the region of the cathode located beneath an  
20 anode, where most of evaporated material would be trapped by the anode rather than flowing to the substrate.

Further, the presence of the shield allows the target evaporation surface of the cathode plate to be constructed of a combination of the coating material and another material, for example an expensive coating material such as titanium or  
25 platinum in the desired erosion zone and an inexpensive material such as steel outside of the erosion zone. The steel portion of the target surface may be shielded by a floating shield of the invention to prevent cathode spot formation and motion thereon, and thus prevent contamination of the coating while optimizing utilization of the expensive coating material.

WO 2005/040451

PCT/US2004/030603

12

In an arc coating apparatus utilizing a magnetic steering system, regions where the transverse magnetic field is low can be shielded in the same manner to exclude movement of the arc spot into these regions and create the desired pattern of erosion. In this embodiment of the invention the target may be placed on the poles of magnetron-type magnetic system of the type described in U.S. Patent No. 4,724,058 issued February 9, 1988 to Morrison, which is incorporated herein by reference. The region of the evaporation surface located about the central part of target cathode, where the tangential component of the magnetic field is too weak to confine arc spots, may be shielded by a floating shield which prevents the arc spot from migrating into the stagnation area created between the magnetic fields generated by the magnetron.

The invention further provides a magnetic focusing system which confines the flow of plasma between magnetic fields generated on opposite sides of the coating chamber. This prevents the plasma from contacting the surface of the housing, to avoid premature deposition, and increases the concentration of plasma in the vicinity of the substrate holder.

In a further embodiment the plasma focusing system can be used to deflect the plasma flow off of the working axis of the cathode, to remove the neutral component of the plasma which otherwise constitutes a contaminant. In this embodiment the plasma focusing coils are disposed in progressively asymmetric relation to the working axis of the cathode, to deflect the flow of plasma along a curvate path toward a substrate holder.

The present invention thus provides a vacuum arc coating apparatus comprising at least one rectangular cathode plate having opposed long sides connected to a negative pole of a current source, the at least one cathode plate having a target surface comprising an evaporation surface or a sputtering surface, or both, a coating chamber in communication with the target surface, a substrate holder within the coating chamber, at least one anode within the coating chamber spaced from the target surface, connected to a positive pole of a current source, and a magnetic deflecting system comprising at least first and second conductors arranged along opposite long sides of the at least one cathode plate, the first conductor carrying a current in a

WO 2005/040451

PCT/US2004/030603

13

direction opposite to a direction of current in the second conductor, the first and second conductors each being disposed in front of and in the vicinity of the target surface so that a magnetic field generated thereby focuses a flow of vapour plasma from the target surface toward the substrate holder, the first conductor being

5 electrically independent of the second steering conductor, wherein by varying a level of current applied through the first conductor relative to the second conductor the flow of vapor plasma shifts toward the coating chamber.

The present invention further provides a vacuum arc coating apparatus comprising at least one magnetron arc source comprising at least one rectangular

10 cathode plate having opposed long sides, connected to a negative pole of a current source, and sets of magnets disposed behind the at least one cathode plate, the at least one cathode plate having a target surface comprising an evaporation surface or a sputtering surface, or both, an anode, a coating chamber in communication with the target surface and a housing, a substrate holder within the coating chamber, a plasma

15 guide disposed between the at least one cathode plate and the coating chamber, the cathode plate being out of optical alignment with the substrate holder, and a set of first focusing conductors disposed in front of and generally parallel to the long sides of the at least one cathode plate, for creating a half-cusp configuration of focusing magnetic field lines converging in front of the target surface along the long sides to extract

20 plasma from the arch-shaped magnetron magnetic fields and direct the plasma toward the coating chamber.

The present invention further provides vacuum arc coating apparatus comprising at least one magnetron arc source comprising at least one rectangular cathode plate having opposed long sides, connected to a negative pole of a current

25 source, and sets of magnets disposed behind the at least one cathode plate, the at least one cathode plate having a target surface comprising an evaporation surface or a sputtering surface, or both, an anode, a coating chamber in communication with the target surface, a substrate holder within the coating chamber, a plasma guide disposed between the at least one cathode plate and the coating chamber, the at least one

30 cathode plate being disposed in the plasma guide, a north pole of the magnetron magnetic field being located at the exit of the filtered arc source and a south pole of

WO 2005/040451

PCT/US2004/030603

14

the magnetron magnetic field being located generally centrally relative to the magnetron, or a south pole of the magnetron magnetic field being located at the exit of the filtered arc source and a north pole of the magnetron magnetic field being located generally centrally relative to the magnetron, whereby magnetic field lines exiting  
5 from the filtered arc source reach the evaporation surface, at least one filtered cathodic arc source out of optical alignment with the substrate holder and adjacent to the at least one magnetron arc source, and a set of conductors disposed in front of and generally parallel to the long sides of the target surface, for creating focusing magnetic field lines to magnetically couple the magnetron arc source to the filtered arc source  
10 and thereby extract plasma from the magnetron and the filtered cathodic arc source and direct the plasma toward the coating chamber.

The present invention further provides a method of controlling a flow of plasma in a vacuum arc coating apparatus comprising at least one magnetron arc source comprising at least one rectangular cathode plate having opposed long sides  
15 and connected to a negative pole of a current source and having a target surface comprising an evaporation surface or a sputtering surface, or both, an anode, and a coating chamber in communication with the target surface containing a substrate holder comprising the steps of: a. generating at least one cathode spot on the target surface to create a plasma, and b. generating a deflecting magnetic field having  
20 deflecting magnetic field lines overlapping with magnetron magnetic field lines generated by the magnetron, the deflecting magnetic field lines and the magnetron magnetic field lines having the same transverse direction, whereby the deflecting magnetic field draws plasma from the magnetron magnetic field and deflects the plasma toward the coating chamber.

25 In a further aspect of the method of the invention, a current through the deflecting conductors on opposite sides of the target surface can be controlled independently.

Further aspects and embodiments of the invention and of apparatus for implementing the methods of the invention will be apparent from the detailed  
30 description which follows.

WO 2005/040451

PCT/US2004/030603

15

Brief Description of the Drawings

In drawings which illustrate by way of example only a preferred embodiment of the invention,

Figure 1 is a schematic cross-section of a prior art large area cathode vacuum arc plasma source having a magnetic steering system disposed behind the cathode plate;

Figure 2 is a partial perspective view illustrating the distribution of magnetic field lines produced by a magnetic steering system according to one embodiment of the invention;

Figure 2a is a schematic elevation illustrating balanced magnetic field lines produced by the magnetic steering system of Figure 2;

Figure 2b is a schematic elevation illustrating an erosion corridor produced by the magnetic steering system of Figure 2 unbalanced in a first direction;

Figure 2c is a schematic elevation illustrating an erosion corridor produced by the magnetic steering system of Figure 2 unbalanced in a second direction;

Figure 3 is a schematic elevation illustrating a variation of the embodiment of Figure 2 in which multiple steering conductors are disposed along the long sides of the cathode plate;

Figure 4 is a plan view of a further preferred embodiment of a large area cathode arc source of the invention;

Figure 5 is a cross-section of the apparatus of Figure 4 taken along the line 5-5;

Figure 6a is a cross-section of the apparatus of Figure 4 taken along the line 6-6;

WO 2005/040451

PCT/US2004/030603

16

Figure 6b is a cross-sectional elevation of a further embodiment of the apparatus of Figure 4 having multiple pairs of steering conductors;

Figure 7a is a plan view of an arc coating apparatus embodying a plasma focusing system according to the invention having a plurality of linear anodes  
5 and a single cathode target;

Figure 7b is a side elevation of the arc coating apparatus of Figure 7a;

Figure 7c is a side elevation of the arc coating apparatus of Figure 7a with plurality of cathode targets installed in the same housing;

Figure 7d is a plan view of an arc coating apparatus of Figure 7c;

10 Figure 8 is a plan view of a variation of the arc coating apparatus of Figure 7a providing neutralizing conductors for modulating the steering and focusing conductors;

Figure 9 is a plan view of an arc coating apparatus embodying a deflecting electromagnetic system according to the invention for guiding cathodic  
15 evaporate to a substrate holder disposed remote from the working axis of the cathode plate;

Figure 10a is a plan view of a dual arc coating apparatus embodying the magnetic steering, focusing and deflecting aspects of the invention;

Figure 10b is a plan view of a dual arc-magnetron coating apparatus  
20 embodying the magnetic steering, focusing and deflecting aspects of the invention;

Figure 10c is a plan view of a dual magnetron coating apparatus embodying the magnetic steering, focusing, deflecting and auxiliary arc ionizing aspects of the invention;

Figure 11 is a cross-sectional side elevation of a further embodiment of  
25 the arc coating apparatus according to the invention;

WO 2005/040451

PCT/US2004/030603

17

Figure 12 is a cutaway front elevation of the arc coating apparatus of Figure 11;

Figure 13 is a rear elevation of the arc coating apparatus of Figure 11;

5 Figure 14a is a partial perspective view of the arc-magnetron coating apparatus embodying the magnetic steering, focusing and deflecting aspects of the invention;

Figure 14b is a cutaway front elevation of the arc-magnetron coating apparatus of Figure 14a;

10 Figure 14c is a cross-sectional side elevation of the arc-magnetron coating apparatus of Figure 14a taken along a longitudinal centre of the magnetron target;

Figure 14d is a cross-sectional side elevation of the arc-magnetron coating apparatus of Figure 14a taken along a transverse centre of the magnetron target;

15 Figure 15 is a schematic plan view of an embodiment of the invention having four magnetrons coupled in a dual filtered-arc source configuration;

Figure 16 is a schematic cross-sectional plan view of a processing chamber having multiple pairs of opposed rectangular filtered arc-magnetron coating stations with loading of the large bearing race in a vertical rotational alignment; and

20 Figures 17a to 17c are schematic elevational views of a magnetron showing the influence of magnetic field lines generated by the magnetron and deflecting conductors.

#### Detailed Description of the Invention

25 Figure 1 illustrates a prior art large area rectangular cathode vacuum arc plasma source of the type described and illustrated in U.S. Patent No. 4,724,058 to Morrison, which is incorporated herein by reference. The apparatus 10 comprises a

WO 2005/040451

PCT/US2004/030603

18

cathode plate 12 having a target surface comprising evaporation surface 14 which may be circumscribed by a confinement member 16 composed of a magnetically permeable material. As described in U.S. Patent No. 5,587,207 issued December 24, 1996 to Gorokhovskiy, which is incorporated herein by reference, an anode 15 disposed  
5 opposite the target surface 14, which may be composed of a metallic or a non-metallic coating material.

A current applied between the cathode 12 and the anode 15 creates an arc which generates an arc spot on the target surface 14. In the prior art apparatus shown the scanning pattern of the cathode spot is controlled by a closed-loop  
10 magnetic field source 18 disposed behind the cathode 12. The magnetic field source 18 establishes magnetic fields 19a, 19b in opposite directions over the target surface 14 which moves the arc spot in a retrograde motion according to the formula

$$V_{cs} = -c[I_{as}(B_t)]$$

in which  $V_{cs}$  is the velocity of the arc spot,  $I_{as}$  is the arc spot current,  $B_t$  is the  
15 strength of the transverse magnetic field, and  $c$  is a coefficient based on the material of the target surface 14. The arc spot thus traces a retrograde path about the cathode plate following the length of the magnetic field source.

When trapped within the static magnetic field produced by the magnetic field source 18, the cathode spot is directed toward the apex of the magnetic field lines 20, the region where the tangential component of a magnetic field is  
20 strongest, which causes the target surface 14 to evaporate along a narrow evaporation corridor 14a. Further, the oppositely oriented magnetic field lines 19a, 19b create a stagnation zone at 22 in which the cathode spot can settle and remain for prolonged periods, eroding the target surface 14 unduly in the stagnation zone 22. Both of these  
25 effects result in poor utilization efficiency of the target surface 14. Accordingly, in the apparatus described in U.S. Patent No. 4,724,058 the magnetic field is activated only intermittently during the coating process, the arc spot being free to scan randomly most of the time. Since the cathode spot is largely self-steering, magnetic fields cannot be used for plasma focusing.

WO 2005/040451

PCT/US2004/030603

19

Figure 2 illustrates a preferred embodiment of a cathode spot steering system 60 according to the invention. In the embodiment illustrated in Figure 2 the steering system 60 is disposed behind the cathode plate 32 (i.e. on the side of the cathode plate 32 opposite to the target evaporation surface 34), which has long sides 32a, 32b and short sides 32c, 32d. The steering system 60 comprises linear conductors 62 and 64 respectively disposed in parallel with the long sides 32a, 32b of the cathode plate 32 having a current  $I_{LS}$  applied thereto in the direction shown, and linear conductors 66 and 68 respectively disposed in parallel with the short sides 32c, 32d of the cathode plate 32 having a current  $I_{SS}$  applied thereto in the direction shown. The conductors 62, 64 are disposed behind the cathode plate in the vicinity of the target surface 34 so that the magnetic fields generated thereby intersect the target surface 34, and thus influence arc spot formation and motion. The steering conductors 62, 64, 66, 68 may alternatively be disposed in front of the cathode plate, as in the embodiment illustrated in Figures 4 to 6, described below. In either case the steering magnetic field source 60 generates a magnetic field defining an erosion zone 70 along the target surface 34.

The configuration and polarities of the magnetic fields generated by the steering conductors 62, 64, 66 and 68 are illustrated by the magnetic field lines in Figure 2. The magnetic field lines projecting above the target surface 34 are arch-shaped, and on opposite sides of the cathode 32 are oriented in opposite directions. Arc spots moving within the erosion zone 70 are attracted toward the apex of the arch-shaped magnetic field lines, where the tangential component of the magnetic field which projects beyond the target surface 34 is strongest. When the current through opposite conductors, for example steering conductors 62 and 64, is equal or balanced (i.e.  $I_1 = I_2$ ), the arc spot travels along a narrow erosion corridor largely confining the erosion zone 70 beneath the apex of the magnetic field lines symmetrically about the longitudinal centre of the cathode plate 32, as shown in Figure 2a.

According to one aspect of the invention, by increasing the current in one steering conductor relative to the current in the steering conductor on the opposite side of the cathode plate 32, the magnetic field becomes unbalanced and the magnetic field lines on the side of the cathode 32 with the weaker magnetic field shift toward

WO 2005/040451

PCT/US2004/030603

20

the side of the cathode 32 with the stronger magnetic field. In the preferred embodiment each linear conductor 62, 64, 66, 68 is thus electrically independent and can be controlled in isolation.

For example, in Figure 2b the current in steering conductor 62 has been increased relative to the current in steering conductor 64, so that  $I_1 < I_2$ . The resulting unbalancing of the strength of the magnetic fields generated thereby distorts the magnetic field generated by the conductor 64 and shifts its magnetic field lines toward the conductor 62. The point of the magnetic field generated by conductor 64 where the tangential component of the transverse magnetic field is strongest has thus shifted away from the side 32a and toward the centre of the cathode 32, and arc spots accordingly trace a path closer to the centre of the cathode 32. By unbalancing the current in conductors 62, 64 so that conductor 64 generates the stronger magnetic field and  $I_1 > I_2$ , the path of the arc spot shifts away from the side 32b and toward the centre of the cathode, as shown in Figure 2c.

The degree of unbalancing, i.e. the current differential between conductors 62 and 64, determines the extent of the magnetic field shift. By unbalancing the conductors 62, 64 at selected current levels and in properly timed intervals coinciding with the motion of the arc spot, a plurality of arc spot paths are created. This substantially increases utilization efficiency of the target surface.

A similar effect is achieved along the short sides 32c, 32d of the cathode 32 by unbalancing the current through the conductors 66, 68. The path of the arc spot will shift toward the centre of the cathode 32 along the side with the weaker magnetic field. However, it will be appreciated that if the cathode plate 32 is narrow enough that the magnetic fields generated along the long sides 32a, 32b by conductors 62, 64 are relatively close together, the conductors 66, 68 along the short sides 32c, 32d may become unnecessary; the arc spot will naturally migrate back and forth between the long magnetic fields, or as the arc spot reaches the end of its path along one long side 32a or 32b the magnetic field can be selectively decreased or momentarily deactivated along that side and the arc spot will move to the other side 32b or 32a where the magnetic field is stronger.

WO 2005/040451

PCT/US2004/030603

21

The closing conductors 62a, 64a, 66a, 68a, which are parallel to the target surface 34 and respectively complete the circuit for each steering conductor 62, 64, 66, 68, are maintained well away from the cathode plate 32 and the housing 38. This ensures that the magnetic fields generated by the closing conductors 62b, 64b, 66b, 68b or 72a, 72b do not influence arc spot formation or plasma flow patterns.

In operation, when an arc is created by applying a current between the anode and the cathode plate, an arc spot generated on the target surface 34 settles in an erosion corridor 70 defined within the steering magnetic fields generated by the steering conductors 62, 64, 66, 68. The arc spot follows a retrograde motion along the erosion zone 70. The magnetic field is periodically unbalanced by a control switch (not shown), which intermittently increases the current through conductor 62 to increase the strength of the magnetic field generated thereby and shift the arc spot path away from the side 32a, and alternately increases the current through conductor 64 to increase the strength of the magnetic field generated thereby and shift the arc spot path away from the side 34a. This effectively widens the erosion zone 70 to increase the utilization efficiency of the target surface, improving the quality of the coating and the durability of the cathode 32.

In a variation of this embodiment, illustrated in Figure 3, a plurality of steering conductors 62b, 62c, 62d and 64b, 64c, 64d are provided respectively along the long sides of the cathode plate 32. In this variation the steering conductors 62b, 62c, 62d and 64b, 64c, 64d are activated or modulated alternatively so that the erosion corridor, being located generally above the currently active steering conductor 62b, 62c or 62d on one side and 64b, 64c or 64d on the other side, can be shifted in a widthwise direction over the cathode plate 32 to increase the breadth of the erosion zone 70.

In the embodiment of Figure 3 as many steering conductors may be provided as the size of the cathode plate 32 will practically allow. One steering conductor 62b, 62c or 62d and 64b, 64c or 64d should be active on each side of the cathode plate 32 at any particular time, in order to avoid creating a stagnation zone in which the cathode spot may become trapped. However, where the conductors on each

WO 2005/040451

PCT/US2004/030603

22

side of the cathode 32 are close together, simultaneously exciting more than one conductor on each side of the cathode 32 can allow for a more elaborate erosion pattern which, properly controlled, can increase the utilization efficiency of the target surface 34 even further.

5 In the operation of this embodiment, when an arc is created by applying a current between the anode and the cathode plate, an arc spot generated on the target surface 34 settles in an erosion corridor 70 defined within the steering magnetic fields generated by the active steering conductors, for example 62b and 64b. The magnetic field is periodically shifted by a control switch (not shown), which switches the  
10 current between the conductors 62b, 62c and 62d on the long side 32a and between the conductors 64b, 64c and 64d on the long side 32b, to thereby and shift the arc spot path to the vicinity of the active steering conductor. This widens the erosion zone 70 to increase the utilization efficiency of the target surface, improving the quality of the coating and the durability of the cathode 32.

15 It will be appreciated that in each of these embodiments the active steering conductor does not need to be deactivated completely when another steering conductor is activated, or fully energized when activated, in order to achieve the desired erosion pattern in the erosion zone 70. The current can be modulated differentially as between the various steering conductors to generate the same result.

20 Figures 4 to 6 illustrate a further embodiment of the invention providing arc spot shielding. An arc coating apparatus 30 is provided with a rectangular cathode plate 32 comprising a target evaporation surface 34 and a supporting plate 36 mounted to a cathode holder 42, within a coating chamber defined by the target surface 34 and a housing 38. In the preferred embodiment the target  
25 surface 34, which may be composed of any suitable metallic or a non-metallic coating material, has long sides 32a, 32b and short sides 32c, 32d and is electrically insulated from the housing 38 by dielectric spacers 39 isolating the cathode holder 42 from the supporting plate 36 and spaced from the housing 38 by a gap 40. The target surface 34 may be formed from different materials, for example titanium and aluminum or  
30 titanium and chromium, integrated in a mosaic fashion along the erosion zone 70 to

WO 2005/040451

PCT/US2004/030603

23

produce a composite metallic plasma for applying coatings such as TiAlN, TiCrN or the like.

The cathode plate 32 is spaced from the cathode holder 42 to create a coolant chamber 44 for circulating a coolant such as water, and is connected to the negative pole of an arc current source (not shown). A conventional high voltage pulse igniter 48 is mounted through a dielectric sleeve traversing the wall of the housing 38.

Suspended from the housing 38 by a mounting assembly 51 is a plurality of linear anodes 50, spaced from the cathode plate 32 and mounted to respective anode holders 52 which may be provided with a coolant channel 53 for circulation of a coolant such as water. The anodes 50 are connected to the positive pole of the arc current sources 46. In the preferred embodiment the anodes 50 each comprise a series of baffles or "fins" 50a which may be disposed generally orthogonally in relation to an anode body 50b, to increase the effective anodic surface area. The fins 50a and anode body 50b are each preferably oriented in a direction parallel to the direction of the plasma flow, i.e. parallel to the direction of any focusing magnetic fields in the vicinity of the anode 50 as described below, to reduce the opportunity for vapour deposition on the anodic surfaces and thus reduce diffusion losses.

Arc spot formation is confined by steering magnetic fields produced by a steering magnetic field source 60 comprising linear conductors 62 and 64 respectively disposed along the long sides 32a, 32b of the cathode plate 32 and linear conductors 66 and 68 respectively disposed along the short sides 32c, 32d of the cathode plate 32. In this embodiment the conductors 66, 68 are disposed behind the cathode plate 32 as in the previous embodiments, but the conductors 62, 64 are disposed in front of the cathode plate 32. The conductors 62, 64 are still disposed in the vicinity of the target surface 34 so that the magnetic fields generated thereby influence arc spot formation and motion, and the operation of the steering system 60 in this embodiment is substantially as described in respect of the embodiment of Figure 2.

WO 2005/040451

PCT/US2004/030603

24

However, in the embodiment of Figures 4 to 6 the steering magnetic fields do not confine arc spots, as in the embodiment of Figure 2, because the magnetic field lines are not arch-shaped and intersect the target surface 34 on only one side, as seen by the magnetic field lines shown in Figure 5. Thus, because of the acute angle principle arc spots are guided toward the central region of the cathode plate 32, away from the acute angle formed where the magnetic field lines intersect the target surface 34. Arc spots therefore have a broader range of motion available in this embodiment. Moreover, in the embodiments in which the steering conductors are located behind the cathode plate 32, in which the portion of the steering magnetic fields projecting above the target surface 34 is closed (i.e. intersects the target surface 34 along both sides), the magnetic fields confine not only the arc spot but also the plasma generated as the target surface 34 evaporates. As shown in Figure 5, by disposing the conductors 62, 64 in front of the target surface 34 the cathodic evaporate has an open path to the substrate holder 6.

Arc spots are thus guided toward the central region of the cathode plate 32, from both long sides 32a, 32b. To avoid creating a stagnation zone in the central region of the cathode plate 32, a conductive shield 54 maintained at floating potential is mounted to each anode holder 52, insulated therefrom and spaced from the target evaporation surface 34, which precludes any cathode spot activity in the central region of the cathode plate 12. Preferably the shield 54 is spaced from the target surface 34 between 2 mm and 6 mm; less than about 2 mm is likely to cause the arc to short circuit through the shield 54 and more than about 6 mm allows the arc spot to creep under the edges of the shield 54. The shield 54 thus prevents evaporation of the cathode 32 in the shadow of the anode 50, confining arc spot formation to an erosion zone 70 surrounding the shadow of the anode 50. This protects the anode 50 from deposition of cathodic evaporate and provides a better distribution of coating material over the substrates (not shown) mounted on the substrate holder 6.

One or more floating shields 54 may be positioned over any selected portion(s) of the target evaporation surface 34, to prevent arc spots from moving into the shielded region. In the embodiment illustrated the shield 54, positioned immediately above the target surface 34 in the vicinity of the anode 50, prevents arc

WO 2005/040451

PCT/US2004/030603

25

spots from forming in or moving into the area of the target surface 34 surrounding the shield 54. This is advantageous in embodiments in which the steering conductors are disposed in front of the cathode plate 32. However, a floating shield 54 can be used to keep arc spots away from any desired region of the cathode plate 32. For example, the

5 floating shield 54 allows the target evaporation surface of the cathode plate to be constructed of more than one material; in this case an expensive coating material such as tungsten or platinum can be omitted from the region beneath the shield 54, and since arc spots will not form or move in that region there is no possibility that the coating will be contaminated.

10 In operation, a current is applied between the anode 50 and the cathode plate 32 and a high pulse voltage applied to igniter 48 initiates a vacuum arc on the target evaporation surface 34 of the cathode plate 32. The arc spot settles in an erosion corridor 70 defined between the steering magnetic fields generated by the conductors 62, 64 and the shielded region of the target surface 34 behind the conductive shields

15 54. The arc spot follows a retrograde motion along one long side 32a or 32b of the target surface 34, and moves to the other long side 32b or 32a traveling beneath the apex of the magnetic field generated by the steering conductor 66 or 68 disposed behind the cathode plate 32. As the target surface 34 evaporates the plasma is guided between the magnetic fields generated by the conductors 62, 64 and flows toward the

20 substrate holder 6, as shown by the arrows in Figure 5.

Because the preferred embodiments of the invention employ a magnetic steering system, it is possible to use a plasma focusing system to guide the cathodic evaporate toward the substrate holder 6. A magnetic field forms a barrier which is largely opaque to plasma. Thus, focusing magnetic fields can be generated

25 about the housing 38 to confine the plasma to a plasma flow region between magnetic fields, and positioning the substrate holder 6 in the plasma flow region to increases the concentration of plasma about the substrates and improves the quality of the coating.

In the embodiment illustrated in Figures 4 to 6 the conductors 62, 64, being disposed in front of the target surface 34 of the cathode plate 32, can also serve

30 as focusing conductors in a plasma focusing system 80. A plasma flow path is

WO 2005/040451

PCT/US2004/030603

26

defined between the magnetic fields generated by the conductors 62, 64, as shown by the magnetic field lines in Figure 5, such that plasma is guided along a central region of the housing 38 to the substrate holder 6. In this embodiment it is advantageous to provide the short side steering conductors 66, 68 with separate power sources, which  
5 allows for the strength of their respective magnetic fields to be varied independently, to compensate for any distortion in the steering magnetic fields caused by the long side steering conductors 62, 64 and thus properly position the arc spot in the erosion corridor 70.

In the embodiment illustrated in Figure 6b, a plurality of pairs of  
10 steering conductors 66, 68 are provided behind a single cathode plate 32, corresponding to the plurality of anodes 50. In this embodiment a separate erosion corridor can be provided for each anode 50, respectively associated with each pair of steering conductors 66, 68 parallel to the short sides of the cathode plate 32, because the two intermediate steering conductors 66, 68 prevent arc spots from migrating past  
15 the center of the cathode plate 32.

To focus the plasma flow, additional plasma focusing conductors may be provided in series to elongate the plasma flow path. For example, Figures 7a to 7d illustrate embodiments of the invention having a plurality of linear anodes 50 in which groups of plasma focusing conductors 82, 84 and 92, 94 are disposed on  
20 opposite sides of the housing 38 and, within each group, progressively further from the cathode 32. This creates a plasma confining zone between the magnetic fields generated on opposite sides of the housing 38, thus defining a plasma flow path between the target surface 34 and the substrate holder 6.

The focusing conductors 82, 84 and 92, 94 are preferably disposed too  
25 far from the cathode plate 32 to influence arc spot formation or motion. Preferably also the focusing conductors in each group 82, 84 or 92, 94 are disposed in closely spaced relation so that their respective magnetic fields overlap to create a continuous magnetic path confining the plasma flow and magnetically isolating the wall of the housing 38 from the plasma flow; otherwise plasma may be trapped against the walls  
30 of the housing 38. As in the case of the steering conductors, the closing conductors

WO 2005/040451

PCT/US2004/030603

27

82a, 84a of the focusing conductors 82, 84 and the closing conductors 92a, 94a of the focusing conductors 92, 94 are maintained well away from the housing 38 and the cathode plate 32 to eliminate any canceling effect of the magnetic fields generated thereby in the region of the housing 38 (plasma duct). In this embodiment it may be  
5 advantageous to provide the short side steering conductors 66, 68 with separate power sources, to compensate for any distortion in the steering magnetic fields caused by the focusing conductors 92, 94.

In the operation of this embodiment, as the target surface 34 evaporates the plasma is concentrated between the focusing magnetic fields generated by  
10 focusing conductors 82, 84 and 92, 94. The plasma thereby flows toward the substrate holder 6 without contacting the housing 38.

The focusing conductors 82, 84 and 92, 94 are preferably independently powered, so that the intensity of the magnetic field generated by each conductor 82, 84, 92, 94 can be varied independently of the others. Closed loop  
15 focusing conductors can be disposed around the housing 38, however in the preferred embodiments illustrated in Figures 7a, 7b pairs of independent focusing conductors 82 and 92, and 84 and 94, respectively, are disposed on opposite sides of the housing 38 parallel to the long sides 32a, 32b of the cathode 32. The closing conductors 82a, 84a, 92a and 94a are maintained well away from the housing 38 and the cathode plate 32.

20 In a further embodiment illustrated in Figure 8 the opposed focusing conductors 82, 92 and 84, 94 are formed from the same closed loop conductor with the focusing conductors 82, 92, 84 and 94 disposed parallel to the long sides 32a, 32b of the cathode 32 with closing conductors 82a, 92a, 84a and 94a disposed parallel to the short sides 32c, 32d of the cathode 32.

25 By connecting focusing conductors 82, 84 and 92, 94 independently to the power supply it is also possible to "raster" the plasma flow by varying the current through opposed focusing conductors 82, 92 and/or 84, 94. This helps to distribute the plasma more uniformly about the plasma duct and to create a more homogeneous plasma mixture. Within the coating chamber the focusing conductors 82, 84 and 92,  
30 94 can be independently activated to deflect plasma toward the substrate holder 6.

WO 2005/040451

PCT/US2004/030603

28

Figure 8 illustrates a mode of reducing the magnetic influence of the closing conductors 82a, 92a using neutralizing conductors 140 comprising closed-loop coils disposed alongside closing conductors 82a, 92a, but in an opposite orientation. When activated the neutralizing conductors 140 eliminate the influence of closing  
5 conductors 82a, 92a on the plasma flow. The neutralizing conductors 140 can also raster the plasma flow slightly in the vicinity of the walls of housing 38 parallel to the short sides 32c, 32d of the target 32.

In all embodiments the closing conductors 82a, 84a, 92a and 94a are maintained well away from the housing 38 and the cathode plate 32 to eliminate any  
10 canceling effect of the magnetic fields generated thereby in the region of the housing 38 (especially the plasma duct region of the housing 38).

The plasma focusing system of the invention can be also used to control vapor plasma flow generated by rectangular magnetron sputtering source, shown in Figures 14a to 14d, in which the target surface is a sputtering surface 34. In  
15 this embodiment, the focusing conductors 62, 64, which are parallel to long side of the target plate 32, are disposed in front of the target plate 32, while the closing conductors 62a, 64a are disposed beside the target plate 32 as shown in Figure 14a. This creates a half-cusp configuration of the focusing magnetic field lines, converging in front of the target plate 32. The closed loop magnetron discharge is created in the  
20 vicinity of the operating surface of the target plate 32 when the power supply 430 is turned on by switch 440. The discharge current is conducted between target plate 32 serving as cathode and surrounding anode 150, as shown schematically in Figures 14c and 14d. The vacuum chamber itself can optionally serve as an anode. The magnetron magnetic field is created in the vicinity of the target surface 34 of the target plate 32  
25 by sets of edge magnets 403, central magnets 402 and end magnets 407. All magnets are preferably installed to a movable magnet holding plate 401.

In the operation of the embodiment of Figures 14a to 14d, argon as a sputtering gas is injected through the gas inlets (not shown) into the vacuum chamber, preferably in the vicinity of magnetron target 32. The high voltage, low current power  
30 supply 430 is activated to supply high negative voltage to the magnetron target 32.

WO 2005/040451

PCT/US2004/030603

29

The magnetron plasma discharge is ignited at a pressure ranging from 0.5mtorr to 0.5torr. The magnetron plasma discharge will be largely confined by the arch-shaped magnetron magnetic field in the vicinity of the magnetron target cathode plate 32, forming a nearly rectangular plasma ring along the gap formed between the edge magnet set 403, the central magnet set 402 and the end magnets 407, best seen in Figure 14b. The erosion zone will be formed by plasma sputtering on the surface of the magnetron target 32 along the path of the magnetron closed-loop discharge, where the plasma density is strongest. The focusing magnetic field created by focusing conductors 62 and 64 will create converging half cusp magnetic field lines in front of the magnetron target 32, which will extract vapor plasma from the magnetron discharge and focus it toward the substrates to be coated on substrate holder 6.

The magnetron sputtering source can be optionally equipped with a high current low voltage arc power supply 435 and arc igniter 48 which allow the source to be used in a cathodic arc evaporation mode. To increase the target utilization rate, the magnetron magnet plate 401 can be attached to a movable shaft 410, which allows the magnets to be moved away from the cathode target 32. In this case the current conductors 64, 62 arranged along the long sides of the target 32 and, independently, current conductors 66, 68 arranged along the short sides of the target 32, are used for steering arc spots along an erosion corridor on the evaporation surface of the cathode target 32.

The plasma focusing system of the invention can also be used as a plasma deflecting system 100, allowing the substrate holder 6 to be disposed remote from the working axis of the cathode plate 32, designated 33 in Figure 9, to eliminate from the plasma the neutral component (macroparticles, clusters and neutral atoms) which are unaffected by the focusing magnetic field and further improve the quality of the coating. As shown in Figure 9, by arranging deflecting conductors 86, 87, 88 and 96, 97, 98 along a curvate housing 38 in a progressively asymmetrical pattern relative to the working axis 33 of the cathode plate 32, the plasma is deflected toward the substrate holder 6 while the inertia of the plasma causes the neutral component to separate from the plasma in the deflection region.

WO 2005/040451

PCT/US2004/030603

30

In Figure 9 the primary vapor plasma source can be cathodic arc source (as shown in Figure 9) or a magnetron source. This Figure 9 thus illustrates how the deflecting conductors 86, 96 87,97, and 88,98 can deflect the vapor plasma flow.

The conductors 86, 87, 88 and 96, 97, 98 thereby create a chain of  
5 deflecting conductors to form a deflecting electromagnetic system. As in the previous embodiments, closing conductors 86a, 87a, 88a and 96a, 97a, 98a are maintained well away from the housing 38 (especially the plasma duct region) and the cathode plate 32. The closing conductors 86a, 87a, 88a and 96a, 97a, 98a may be disposed on the same side of the housing 38 as the deflecting conductors 86, 87, 88 and 96, 97, 98 of  
10 the deflecting system, for example by disposing the closing conductors 86a, 87a, 88a and 96a, 97a, 98a well above or below the level of the housing 38. Alternatively the closing conductors 86a, 87a, 88a and 96a, 97a, 98a may be disposed on the opposite side of the housing 38 but remote therefrom, in which case it is preferable that the distance S between the closing conductors and focusing conductors arranged along  
15 opposite sides of the housing (for example focusing conductors 86, 87, 88 and closing conductors 96a, 97a, 98a) ranges from 1.5H to 3H where H is the width (transverse) of the housing 38.

In the operation of this embodiment, as the target surface 34 evaporates the plasma is concentrated between the magnetic fields generated by the conductors  
20 62, 64 and flows into the deflection region defined between the magnetic fields generated by deflecting conductors 86, 87, 88 and 96, 97, 98. The plasma is thereby deflected along a flow path coinciding with the asymmetrical pattern of the deflecting conductors 86, 87, 88 and 96, 97, 98 and flows toward the substrate holder 6 without contacting the housing 38. The plasma remains confined between magnetic fields  
25 and is thereby deflected away from the working axis 33 of the cathode plate 32. The neutral component continues in a generally straight direction and settles on an interior wall of the housing 38 in the vicinity of the working axis 33 of the cathode plate 32, while the plasma continues along the plasma duct into the coating chamber to the substrate holder 6.

WO 2005/040451

PCT/US2004/030603

31

Figure 10a illustrates a preferred embodiment of an arc coating apparatus according to the invention, providing a pair of cathode plates 32 disposed in a cathode chamber at opposite ends of the housing 38, in communication with the substrate holder 6 through a parallelepipedal plasma duct 31. Internal linear anodes 50  
5 configured as described above are suspended above each target surface 34, separated therefrom by a shield 54. Anodes 50 are defined herein as "internal" because they are disposed within the plasma duct, which is defined between the cathode plates 32 and the substrate holder 6.

A further internal anode, deflecting electrode 120 comprising a linear  
10 plate 122 having baffles 124, is disposed along the plasma duct 31 at the approximate center between the two cathode plates 32. The baffles increase the anodic surface area, effectively functioning as a chain of internal anodes, which provides better stabilization and steering of arc spots. They also serve to trap macroparticles emitted from the evaporation surface 34. As in the previous embodiment, the baffles 124 are  
15 oriented as much as possible parallel to the direction of the magnetic field to reduce diffusion losses. This "dividing" anode 120 also serves to repel ions and thus deflect the plasma streams toward the substrate holder 6.

In this embodiment focusing conductors 82, 84, 92 and 94 are disposed parallel to the long sides 32a, 32b of the cathode plates both about the regions in front  
20 of the cathode plates 32 and about the exit of the plasma duct 31 in the coating chamber. In between the sets of focusing conductors 82, 92 and 84, 94, deflecting conductors 86, 96 are disposed about the portion of the housing 38 where the plasma duct 31 turns toward the axis of the substrate holder 6, i.e. adjacent to a portion of the housing 38 containing the cathode plates 12, creating opposed magnetic cusps  
25 directed perpendicular to the axis of the cathode chamber, to thus deflect plasma toward the substrate holder 6. In the embodiment shown the closing conductors 82a, 84a, 86a, 92a, 94a and 96a must be disposed remote from the plasma duct 31 in order to ensure that the cathode plates 32 are disposed only within the magnetic cusps generated by the focusing and deflecting conductors 82, 84, 92, 94 and 86, 96, so that  
30 cathodic evaporate is drawn into the plasma duct 31 and not toward the back wall of the housing 38. Alternatively, as in the embodiment of Figure 9 the closing conductors

WO 2005/040451

PCT/US2004/030603

32

82a, 84a, 86a and 92a, 94a, 96a may be disposed on the opposite side of the housing 38 but remote therefrom.

The embodiment of Figure 10a also provides one or more external anodes 130 surrounding the substrate holder 6. Anodes 130 are defined herein as "external" because they are disposed outside of the plasma duct 31. Thus, the external anodes 130 do not deflect the plasma, but instead repel ions to prevent diffusion losses on the walls of the housing 38 and prolong ionization of the coating material to improve coating efficiency. Such external anodes 130 can also be provided about any desired portion of the housing 38; Additionally the coating chamber itself, or some portion thereof, may be grounded to serve as an anode.

Further, since the housing 38 is insulated from the cathode plates 32 by dielectric spacers 39, the housing 38 may be left at floating potential as shown in the Figures. Alternatively, providing a floating potential screen or shielding (not shown) between the cathode 32 and the housing 38 to prevent the arc from moving into a gap between the cathode 32 and the housing, will effectively turning the housing 38 into an external or surrounding anode.

The internal anodes 32, 120 and external anode 130 are preferably electrically isolated and thus each is provided with an independent power supply, which allows for better control over their independent functions.

It is also possible to differentially activate the focusing conductors 82, 84 and 92, 94 to trap the metal vapour component of the plasma within the plasma duct while allowing the electron current to flow freely through the coating chamber to the auxiliary anodes 130 surrounding the substrate holder 6. This mode of operation is a "plasma immersed" mode, which provides a high degree of ionization and activation of the gaseous plasma environment in the coating chamber without deposition of metal cathodic arc plasma coatings. The plasma immersed mode supports several different types of plasma processes, such as fast ion cleaning, ion nitriding, ion implantation, and arc plasma-assisted low pressure CVD coating processes. For example, the first stage of a particular coating process may require ion cleaning. The cathodic arc sources 34 may be used as a powerful electron emitters, to

WO 2005/040451

PCT/US2004/030603

33

extract electron current from the cathode to the external anode 130 surrounding the substrate holder 6, providing a plasma immersed environment for fast ion cleaning. Argon, nitrogen, methane etc. may be injected as a plasma-created gas in conjunction with an RF generator providing a self bias potential at the substrate holder for

5 effective ion bombardment, as illustrated by the examples.

Magnetron sputtering plasma sources 400 can be also used as primary vapor plasma sources in a large area filtered plasma source embodiment of the invention, as illustrated in Figure 10b. In this embodiment a magnetron magnetic field is created by a set of magnetron magnets 402, 403 attached to a magnet holding plate

10 401 disposed behind the cathode target plate 32. The magnetron magnetic field must overlap and be directed in the same direction as the focusing magnetic field created by magnetic conductors 82, 84, and 92, 94. This allows for the extraction of an increased amount of magnetron metal sputtering plasma from the magnetron discharge area toward the plasma-guide portion of the electro-magnetic vapor plasma filter chamber

15 500. The mixed vapor-gaseous plasma flow will be confined in a curvilinear magnetic field created by focusing conductors 82, 84 and 92, 94 and deflecting conductors 86, 96. In this embodiment the magnetron targets 32 are positioned in a magnetic half-cusp area on a side of plasma guide chamber 500 where the magnetic force lines converge toward the dividing anode 120. This ensures that all vapor-gaseous plasma

20 extracted from the magnetron discharge will be focused and directed toward the substrates to be coated on substrate holder 6, while neutral droplets and macroparticles are removed from the plasma flow and trapped by baffles 124.

Auxiliary arc cathodes (not shown) can be installed elsewhere in the coating apparatus, out of optical alignment from the magnetron targets 32. For

25 example, Figure 10c shows a thermionic hollow cathode 510 installed in the coating chamber, to establish an auxiliary arc discharge between the auxiliary cathode 510 and the magnetron anodes 150. This results in an increase of the ionization rate of the magnetron discharge plasma while also increasing the ionization rate of the gaseous component of the plasma environment in the coating chamber. This provides for

30 magnetron sputtering at lower operating pressures, and improves coating quality by increasing ionization and activation of the vapor-gaseous plasma environment, while

WO 2005/040451

PCT/US2004/030603

34

eliminating droplets, macroparticles and neutral clusters from metal-gaseous vapor plasma flow.

The filtered vapor plasma embodiment can optionally have both magnetron sources 400 and cathodic arc sources 34 as primary vapor plasma sources, as illustrated in Figure 10b. In this embodiment the targets 32 are provided with additional high current low voltage power supplies 46 connected to the cathode target plate 32 via switches 445 and an arc igniter 48. On each side the magnetron high voltage low current power supply 430 is connected to the target plate 32 via switch 440. The magnetron magnet set can preferably be moved away from the target 32 by using a shaft 410 attached to the magnet holding plate 401.

In the operation of this embodiment in a filtered magnetron sputtering mode, argon as a sputtering gas is injected through argon inlets (not shown) in the vicinity of both magnetron target plates 32 installed at opposite sides of the filtered plasma arc source apparatus. A reactive gas (nitrogen, acetylene) can be optionally supplied into the coating chamber, for deposition of cermet coatings (TiN, TiC, TiCN etc.). The switch 445 is disconnected and the arc power supply 46 is turned off. The switch 440 is activated to connect the negative pole of the magnetron power supply 430 to the target plate 32. The magnetron plasma discharge will be largely confined by the arch-shaped magnetron magnetic field in the vicinity of the magnetron target cathode plate 32, forming a generally rectangular plasma ring along the gap between the edge magnet set 403, the central magnet set 402 and the end magnets(not seen in Figures 10b or 10c). An erosion zone is formed by plasma sputtering on the evaporation surface of the magnetron target 32 along the path of the magnetron closed loop discharge, where the plasma density is strongest. The focusing magnetic field created by focusing conductors 82, 84 and 92, 94 will create converging magnetic field lines in front of the magnetron targets 32, i.e. over the target surface, which will extract vapor plasma flux from the magnetron discharge and focus it toward the plasma-guide portion of the electro-magnetic vapor plasma filter chamber 500. This vapor plasma flux will be further confined into the converging magnetic half-cusp field, which will deflect it toward the coating chamber where substrates to be coated are installed on substrate holder 6. The focusing conductors 82, 84 and 92,94 installed

WO 2005/040451

PCT/US2004/030603

35

at the exit of the plasma-guide will focus the vapor plasma toward the substrates to be coated. The dividing anode 122 will repel metal ions, effectively diverting the ion trajectories toward the coating chamber. Macroparticles and neutral vapor atoms will be trapped by baffles 124, installed at the dividing anode plate 120. When the

5 auxiliary arc discharge is activated between the thermionic cathode 510 and magnetron anodes 150, the ionization rate will be increased in the vicinity of the magnetron targets 32. That increases the productivity of magnetron sputtering, as well as reduces the operating pressure of the magnetron discharge. The electromagnetic filter of this invention has higher conductance at lower pressures due to a reduced

10 frequency of collisions between ions and other atomic particles. This results in a higher ion flux at the filter exit, and thus higher productivity of the filtered magnetron sputtering process.

In a filtered cathodic arc evaporation mode, the switch 440 is opened to disconnect the magnetron power supply 430, and instead the switch 445 connecting

15 the arc power supply 46 to the cathode target plate 32 is closed. When the arc power supply 46 is turned on, the arc igniter 48 will ignite the cathodic arc discharge at the evaporation surface of the cathode target plate 32. A reactive gas can optionally be supplied to the coating chamber for deposition cermet coatings. The magnetron magnets 402, 403 will be moved away from the target plate 32 area by shaft 410

20 supporting the magnet holding plate 401. Cathodic arc spots will be steered by magnetic conductors 82, 84 and 92, 94 parallel to the long side of the targets 32 and, independently by the coils 66, 68 parallel to the short side of the targets 32. This will provide the maximum target utilization rate and arc spot confinement to the wide erosion corridor area on the evaporation surface of the target plate 32. At the same

25 time the steering/focusing conductors 82, 84 and 92, 94 will focus the arc vapor plasma toward the magnetic half-cusp area created by deflecting conductors 86, 96. The deflected plasma flow will be further focused by focusing conductors 82, 84 and 92, 94 installed at the exit of the plasma-guide chamber toward substrates to be coated installed on substrate holder 6. An auxiliary anode 130 can be used to improve the

30 ionization and activation rate of the gaseous component of the vapor-gaseous flow.

WO 2005/040451

PCT/US2004/030603

36

Figures 7c and 7d illustrate a further embodiment of the invention, similar to the embodiment of Figures 7a and 7b but providing multiple rectangular cathode targets incorporated in one rectangular cathodic arc source unit. Housing 38 contains two rectangular cathode assemblies consisting of target plates 34 attached to water-cooled target holder and vacuum arc igniters 170. Each cathode target assembly is surrounding by an insulated shield 140, which prevents cathodic arc spots from moving toward side surface of the cathode assembly. Central anode 50 can be optionally installed in front of the cathode target plate 32. The insulated shield 54 can be installed in a central area of the target plate 32, to prevent cathodic arc spots from moving toward central area of the target where the steering magnetic field component that is tangential to the plate surface 34 is not sufficient to confine arc spots within the erosion corridor 200. Two pairs of focusing magnetic coils 84 and 62 are using to steer cathodic arc spots along long sides of the targets 32, while simultaneously focusing the plasma flow toward the substrate holder 6 installed in the main vacuum chamber. Another pair of magnetic coils 66, 68 is disposed on a backside of each cathode assembly. The linear conductors 66, 68 are parallel to the short sides 32c, 32d of the cathode targets 32, providing steering of cathodic arc spots along short sides of the target surface 34. Conductors 66, 68 must be installed with opposite polarities, providing steering of cathodic arc spots in the same direction as adjacent focusing conductors 62, 84 steering cathodic arc spots along the erosion corridor 200. Surrounding anodes 150 can be optionally sectioned or partitioned, providing independent anodic current circuits for cathodic arc spots located both near the short sides 32c or 32d of the target plate 32 (anodic pair 151-151a in the embodiment shown in Figure 7d) and long sides 32a or 32b of the cathode target 32 (anodic pair 152-152a in the embodiment shown in Figure 7d). This also allows for the detection of cathodic arc spots stagnating near the short sides or long sides of the target surface 34. As soon cathodic arc spots are located near either short or long side of the target surface 34 for time longer than  $t_s \sim l_s/v_s$ , (where  $l_s$  is a length of a short or long side of the cathode target plate 34,  $v_s$  is a velocity of a movement of cathodic arc spots under influence of steering magnetic field), the arc current can be turned off to eliminate the arc spots, followed by re-ignition of the arc by igniters 170. Sectioning or partitioning the anodes, including both surrounding 151, 152 and central 50, allows for the optimal

WO 2005/040451

PCT/US2004/030603

37

distribution anodic arc current to provide maximum reliability of steering of arc spots inside of erosion corridor 200.

Alternatively, instead of a shield (either a shield 140 around the cathode plate 32 or a shield 54 covering the stagnation zone in front of the evaporation surface 34), the cathode plate 32 can be surrounded by a material that has a very low cathodic arc spot sustainability, or this material can be inserted in the area of the cathode plate 32 where arc spots are stagnating. For example tungsten, molybdenum, boron nitride-based ceramics etc., can be used to prevent arc spots from moving in undesirable areas of the evaporation surface 34.

Figures 11 to 13 illustrate a further embodiment of the invention providing local correctional magnets 200 and 210 for guiding the arc spot between one long side 32a of the cathode plate 32 and the other long side 32b, and providing a different anode arrangement.

Short side correctional magnets 200 preferably each comprise at least one magnetic coil 202 surrounding an electromagnetic core 204, and are respectively disposed along the short sides 32c, 32d of the cathode plate 32. The core 202 concentrates the magnetic field generated by the coil 202, so that when the coil 202 is activated the arc spot is constrained to move along the arc-shaped magnetic field lines which extend over the short side 32c or 32d of the cathode plate 32.

In this embodiment long side correctional magnets 210 are also provided along both long sides 32a, 32b of the cathode plate 32, near the short sides 32c, 32d, to similarly constrain the motion of the arc spot as the arc spot nears the short sides 32c, 32d. Long side correctional magnets 210 similarly preferably each comprise at least one magnetic coil 212 surrounding an electromagnetic core 214 which concentrates the magnetic field generated by the coil 212, so that when the coil 212 is activated the arc spot is constrained to move across the magnetic field lines in a direction transversal to the arc-shaped magnetic field lines which extend over the ends of the long side 32a or 32b.

WO 2005/040451

PCT/US2004/030603

38

The directions of the magnetic field lines generated by the correctional magnets 200, 210 must correspond to the motion of the arc spot along the long sides 32a, 32b as determined by the steering conductors 66, 68 (shown in Figure 11). The correctional magnets 200, 210 act on the arc spot only as it nears and traverses the short sides 32c, 32d of the cathode plate 32, to maintain an uninterrupted steering pattern about the cathode plate 32. The strength of the magnetic fields generated by the correctional magnets 200, 210 can be varied by varying the current through the coils 202, 212 or by providing additional coils (not shown) surrounding the cores 204, 214 which can be selectively activated to superimpose an additional magnetic field onto the core 204 or 214.

In this embodiment a linear internal anode 220 comprises a series of anode blocks 222 and 230. Interior anode blocks 222 provide an anode plate 224 and baffles 226 disposed generally orthogonally in relation to an anode plate 224. As in the previous embodiments the anode plate 224 and baffles 226 are each oriented in a direction parallel to the direction of the plasma flow. The anode 220 further includes end anode blocks 230, preferably comprising solid water-cooled blocks, which serve to isolate the interior regions of the anode 220 from cathodic evaporate eroded from the short sides 32c, 32d of the cathode plate 32. The use of separate "blocks" helps to better distribute the arc current and reduces reliance upon a single anode body.

The anode blocks 222, 230 are preferably independently controlled by separate power supplies 227 disposed through water-cooled anode pipes 229, mounted to and insulated from the housing (not shown) by insulating spacers 228. The strength of the current through an anode block 222 or 230 determines the absence or presence of an arc spot, and thus suitable software can be employed to raster or scan through the blocks 222, 230 within the anode 220 in concert with the motion of the arc spot about the erosion zone 70. This arrangement helps to reduce the interval during which the arc spot is passing from one long side of the cathode 32 to the other. Moreover, if the arc spot stagnates at any point along the erosion corridor 70, the power supply to an adjacent anode block 222 or 230 can be deactivated or reduced, and/or the power supply to a more remote anode block 222 or 230 can be activated or increased, to keep the arc spot in motion.

WO 2005/040451

PCT/US2004/030603

39

The linear focusing conductors 82 and 84 shown in Figure 12 (partially concealed by the flange 250) are respectively disposed in front of the evaporation surface along the long sides 32a, 32b of the cathode plate 32. Focusing conductors 82, 84 produce a tangential magnetic field which steers (drags) the arc spot along long sides 32a, 32b of the cathode plate 32. Because they are disposed in front of the evaporation surface 34, the focusing conductors 82, 84 create a magnetic cusp directed toward the coating chamber 38 (similar to that indicated by the arrows Figure 5). The cusp configuration tends to guide arc spots toward the center of the cathode 32, which renders the shield 54 particularly advantageous in this embodiment as it prevents the arc spot from moving into the shadow of the anode 220, where the magnetic field lines are generally perpendicular to the evaporation surface 34 and without the shield 54 would create a stagnation zone in the center region of the cathode 32.

In this embodiment the closing conductors 82a, 84a are disposed behind the evaporation surface 34 along the long sides 32a, 32b of the cathode plate 32 produce a magnetic field having an arch shape over the evaporation surface 34, which balance the acute cusp-shaped magnetic field lines produced by the focusing conductors 82, 84 and act in conjunction with the steering conductors 66, 68 respectively disposed along the short sides 32d, 32c of the cathode plate 32, along with the correctional magnets 200, 210 which also guide arc spots along the short sides 32d, 32c of the cathode plate 32, to guide arc spots in the same direction around the erosion zone 70.

Thus, the conductive shield 54 spaced from the target evaporation surface 34, together with a border shield 55 disposed about the periphery of the cathode plate 32, precludes any cathode spot activity outside of the desired erosion zone 70. In the embodiment shown an internal shield 57 is provided beneath the shield 54, which also serves to prevent cathode spot activity in the shadow of the anode 220.

In the embodiment of Figures 11 to 13 a surrounding anode 240 is provided around the evaporation surface 34, generally orthogonally thereto. The surrounding anode 240, which is disposed in front of the evaporation surface 34, becomes a plasma-immersed anode which improves current exposure to the plasma

WO 2005/040451

PCT/US2004/030603

40

flow and provides a more stable arc current surrounding the primary anode 220. The apparatus of the invention will operate with either the "internal" anode 220 or the surrounding anode 240; however, operation of the apparatus is improved by employing both anodes 220, 240 simultaneously.

5                    Figures 14a through 14d illustrate an embodiment of the arc-magnetron coating apparatus having the magnetic steering, focusing and deflecting aspects of the invention.

                    Figure 15 illustrates an embodiment of the invention having four magnetrons 400, each magnetically coupled with a dual rectangular filtered-arc source  
10    34. In the embodiment illustrated 4 dual rectangular filtered arc sources 34 are respectively magnetically coupled with 4 unbalanced rectangular magnetrons 400. In this embodiment the magnetron sources 400 are in optical alignment with the substrates on the substrate holder 6, as in a conventional coating process. Each dual  
15    filtered-arc source has at least two rectangular primary arc sources 34 installed at the opposite flanges of the filtered arc plasma guide chamber. The anode separator 122 divides the plasma guide chamber and provides a set of baffles 124 for trapping macroparticles, droplets and neutral atoms and clusters, generated by primary cathodic  
20    arc sources. Each rectangular cathodic arc source has focusing/steering coils installed parallel to the long side of the cathode target and back coils installed parallel to the short side of the targets 32 near end of the targets 32. In this embodiment focusing  
25    conductors 82, 84 and 92, 94 focus the flow of plasma from of the filtered arc sources 34, as described above, whereas conductors 86 near the exit of the plasma guide 31 are adjacent to both the filtered arc sources 34 and the magnetron source 400 and thus magnetically couple the magnetron source 400 with the adjacent filtered arc source 34  
30    to simultaneously deflect the flow of plasma from both the magnetron arc source 400 and the filtered arc source 34 toward the coating chamber. As shown by the magnetic field lines in Figure 15, the magnetron arc sources are magnetically coupled to the filtered arc sources by the adjacent focusing conductors 86, which focus and deflect the plasma toward the substrate holder 6. The substrate holder 6 comprises a central substrate platform with multiple double rotation stations, and has near equal access to

WO 2005/040451

PCT/US2004/030603

41

incoming vapor plasma fluxes from both filtered arc sources 34 and magnetron sources 400, which simplifies the control of coating composition and architecture.

The ability to independently vary the current flowing through focusing conductors 84, 94 on each side of the cathode 34 allows a rectangular cathode plate 32 to be used in a filtered arc arrangement, i.e. disposed out of optical alignment with the substrate holder 6. By increasing the current through the conductors 84, 94 on the side of the cathode 34 adjacent to the plasma duct 31 relative to the conductors 84, 94 on the side of the cathode 34 opposite the plasma duct 31, the plasma is deflected toward the plasma duct 31 and thus toward the substrate holder 6. Neutral particles are not deflected, and are thus trapped in the baffles 124 of the anode divider 122.

For example, Figure 17a illustrates the manner in which plasma becomes trapped under the closed-loop magnetic field lines 600 generated by the magnetron 400. Plasma has a very low diffusivity across the magnetic field lines of the closed magnetic loops 600 of the magnetron, but a very high diffusivity along the magnetic field lines 600. The magnetic field lines 600 effectively become like a "track" which confines the plasma flux (unlike neutral particles, shown as dashed arrows, which are unaffected by the magnetic field lines 600). Therefore, the magnetic field lines 602 generated by the deflecting conductors 84, which have the same transverse direction as the magnetic field lines 600 generated by the magnetron 400, draw the vapor plasma flux away from the target surface and deflect it toward the substrate holder 6.

If the deflecting conductors 84 are disposed immediately in front of the cathode plate 32, as shown in Figure 17b, the magnetic field lines 602 in front of the conductors 84 overlap the magnetron magnetic field lines 600 and draw plasma away from the center of the magnetron 400 and toward the substrate holder 6 in a dispersed fashion. This arrangement is most suitable for coupling the magnetron 400 with a filtered arc source 34, because the deflecting magnetic field lines 602 simultaneously draw plasma from both sources and deflect it toward the coating chamber.

If the deflecting conductors 84 are disposed in front of the cathode plate 32 but spaced from the target surface, as shown in Figure 17c, the magnetic field

WO 2005/040451

PCT/US2004/030603

42

lines 604 rearward of the conductors 84 overlap the magnetron magnetic field lines and draw plasma toward the center of the magnetron 400 and toward the substrate holder 6, but in a much more confined linear stream. This arrangement provides a more focused deflection toward the substrate holder 6 in a filtered embodiment, but the linear stream of plasma does not conform as readily to the substrate shape (for example, inside surfaces of the substrate may not get coated in this embodiment, whereas the more dispersed magnetically deflected plasma in Figure 17b coats a wider area more uniformly).

The ability to independently control the current through the deflecting conductors 84 is very advantageous in these embodiments. It allows much greater control over the flow of plasma, and by alternately varying the level of current through the opposed deflecting conductors 34, allows the plasma to be rastered back and forth over the substrate holder 6 to ensure a uniform coating over the substrates. This also allows for the mixing of plasmas having different metal vapor compositions, for example one type of metal vapor from the filtered cathodic arc source 34 and another type of metal vapor from the adjacent magnetron source 400, in a readily controllable manner. This is necessary for the deposition of composite materials.

In the embodiment shown in Figure 16, the substrates to be coated are large diameter bearing races. For coating the inside surface of the race the race is loaded throughout the back flange of the dual filtered-arc source and rotated around its axis using a set of race drivers and guide idler (not shown) installed in the race drive tank appendage. This embodiment operates in the same manner as the embodiment of Figures 15. The filtered arc source 34 is out of optical alignment from the substrate holder 6, to thereby eliminate droplets (which are neutral and therefore not deflected by the focusing and deflecting magnetic coil 84, 94) and trapped by baffles (not shown) installed in the plasma guide chamber and at the anode separator. The filtered arc source 34 is magnetically coupled with the magnetron 400; thus if the north pole of the magnetic field is located at the exit of filtered arc source then the central pole of the magnetron magnetic system has to be south (at the top butt-end). In this case magnetic field lines exiting from the filtered arc source 34 will end at the surface of the magnetron target 32. For the same reason, the direction of the current in the

WO 2005/040451

PCT/US2004/030603

43

focusing (exit) current conductor of the filtered arc source has to be the same as the direction of the current in the adjacent focusing conductor of the adjacent magnetron.

Also, in this embodiment the substrate to be coated is a large ring and both the ID and OD surfaces of this ring are to be coated. Accordingly, instead of  
5 loading the substrate into the coating chamber and installing the substrate platform coaxial to the coating chamber, the substrates are loaded through a back flange of the plasma guide chamber of the filtered arc source, in vertical alignment. Thus, only the portion of the ring positioned in front of the filtered arc source opening will be subjected to coating deposition, from the primary cathodic arc sources 34 on both  
10 sides and from the magnetron sources 400 on both sides. The rest of the ring, which is disposed inside of the plasma guide chamber, is shielded and not exposed to the coating process. The substrate bearing race is rotated around its axis, providing a uniform filtered arc-magnetron coating of the ID surface. For coating the OD surface, the ring is moved forward toward the opposite filtered arc-magnetron station and  
15 coating proceeds in that position in the same manner, but from the opposite filtered arc-magnetron source.

#### Example 1

Deposition of a diamond-like coating (DLC) on set of knives such as scalpels, razors, knives for cutting papers using two rectangular arc sources mounted  
20 in the dual rectangular plasma guide chamber of Fig. 10 with deposition zone 500 mm height x 300 mm width. The array of knives was installed on a rotating substrate platform facing the filtered arc source over the entire area of the deposition zone, with uniform rotation speed between about 10 to 20 rpm. A graphite rectangular plate evaporation target was attached to the cathode plate assembly. The current in the  
25 vertical steering conductors was set to 2000 amps, and the current in the horizontal steering conductors was set to 1300 amps. The arc current between the cathode and the primary (internal) anode plate was set to 300 amps. After igniting the arc with an impulse high voltage igniter, the arc spot began moving along an erosion corridor with an average speed ranging from 20 to 30 cm/s. About three to five cathodic arc spots

WO 2005/040451

PCT/US2004/030603

44

subsisted simultaneously on the target surface. The current in the deflecting coils was set to 1500 amps each.

The first stage of the process involved ion cleaning. At this stage the cathodic arc sources were used as a powerful electron emitters. The deflecting  
5 conductors were turned off and electron current was extracted from the cathode to the auxiliary (external) anode surrounding the substrate platform, providing a plasma immersed environment for fast ion cleaning. Argon was injected as a plasma-created gas with pressure of about  $4 \times 10^{-2}$  Pa and an RF generator provided a 400 volt self bias potential at the substrate platform for effective ion bombardment.

10 During the deposition stage the pressure in the vacuum chamber was set to  $10^{-3}$  Pa. The RF generator having a 13.56 MHz frequency provided a self bias potential ranging from 40 V to 60 V during deposition. The deflecting coils were turned off during deposition periodically with a duty cycle of 20s on/5s off to prevent overheating of the coating. The time of deposition was 20 minutes. The thickness of  
15 the coating, as measured by micro cross section, ranged from 0.3 to 0.35 mkm which corresponds to a deposition rate of about 1 mkm/hr with a uniformity of +/- 10%.

#### Example 2

Deposition of graphite coating on molybdenum glass for using as a substrate for flat panel display using rectangular molybdenum glass plates with  
20 dimensions 400 mm height x 200 mm width x 3 mm thick installed vertically on the rotating substrate platform. Each glass plate was attached to a metal plate-holder and a self bias of about 150 V was applied to the substrate platform using an RF generator with a 13.56 MHz frequency. The dual filtered cathodic arc source of Figure 10 was provided with one aluminum target evaporation surface and one graphite target  
25 evaporation surface. The pressure during coating deposition was maintained at about  $10^{-3}$  Pa. The temperature during deposition of the graphite coating was about 400° C, provided by an array of radiative electrical heaters.

In the first stage the arc was ignited on the aluminum target, providing an aluminum sublayer with thickness about 50 nm. In the second stage a graphite

WO 2005/040451

PCT/US2004/030603

45

coating with thickness about 150 nm was deposited over the aluminum sublayer during a coating interval of 30 minutes.

### Example 3

Deposition of TiAlN coatings on an array of hobs and end mills. The array of hobs and end mills was installed on substrate platform facing the filtered arc source exit over the entire area of the deposition zone, the substrate platform having a double (satellite) rotation with platform rotation speed 12 rpm. The dual rectangular filtered arc source of Figure 10 was provided with an aluminum target evaporation surface mounted to one cathode and a titanium target evaporation surface mounted to the second cathode, for deposition of the TiAlN coating. The current for the titanium target was set at about 150 amps while current for the aluminum target was set at about 60 amps.

In the first stage the current of the auxiliary (external) anode was set at about 70 amps, providing a high density gaseous plasma immersed environment during both fast ion cleaning and coating deposition. The self bias potential of substrate platform provided by a RF 13.56 MHz generator was maintained at about 400 volts during ion cleaning in argon, and at about 40 volts during deposition of TiAlN coating in nitrogen. The time for ion cleaning was 5 minutes, and for deposition was about 2 hours. The argon pressure during ion cleaning was set at  $6 \times 10^{-2}$  Pa of argon, and for the deposition stage it was set at  $2 \times 10^{-2}$  Pa of nitrogen. The deposition rate for TiAlN coating for double rotated hobs and end mills was found to be about 1-1.5  $\mu\text{m/hr}$ .

### Example 4

Deposition of multi-layer coatings on dies and molds. An array of forging dies and extrusion molds was installed on the substrate platform with uniform rotation speed 20 rpm facing the filtered arc source exit in the dual rectangular filtered arc source of Figure 10, for the deposition of Ti/TiN multi-layer coating with thickness ratio 0.05  $\mu\text{m}$  of Ti and 0.3  $\mu\text{m}$  of TiN. Before deposition of the coatings fast ion cleaning and arc plasma immersed ion nitriding was performed to provide

WO 2005/040451

PCT/US2004/030603

46

gradually increased hardness of near surface layer in a transition zone between bulk material of coating parts and the coating layer. The thickness of nitriding layer was about 40  $\mu\text{m}$ , provided by an auxiliary arc discharge with the current of auxiliary (external) anode set at about 90 amps and a pressure of nitrogen set at about  $6 \times 10^{-2}$  Pa. The number of coating layers was 11 with total thickness about 3.5  $\mu\text{m}$ . The current of the auxiliary anode during the deposition stage was set at about 120 amps, providing maximum total current at both titanium targets of about 500 amps. The DC bias during the ion cleaning/ion nitriding stage was set at about 200 volts, and during the deposition stage the voltage was reduced to 40 volts. The temperature of substrates was maintained at about 400° C during all stages of the vacuum plasma treatment cycle.

#### Example 5

Filtered magnetron deposition of cubic boron nitride (cBN) coatings. The coating system shown in Figure 10c was used for deposition of predominantly cubic boron nitride coatings. Magnetron targets made of  $\text{B}_4\text{C}$  were used for deposition cBN coating. The rectangular magnetron erosion area was 320 x 80  $\text{mm}^2$ . The carbide inserts were installed on substrate holder 6. The thermionic cathode ionizer 510 was activated to ionize and activate the plasma environment during an ion cleaning stage. The high current low voltage thermionic auxiliary arc power supply 46 was connected between thermionic hollow cathode 510 installed in the coating chamber and magnetron anodes 150. This also allowed for an increase in the ionization rate of the magnetron plasma discharge and reduction of the magnetron operating pressure. The thermionic arc current was set to 80 amperes per each magnetron anode 150. The argon pressure in a coating chamber was set to 1 mtorr during the ion cleaning stage. The bias voltage was set to 250 volts during the ion cleaning stage. The ion cleaning stage lasted 30 minutes, during which the substrate temperature was set to 200 °C. During the ion cleaning stage the deflecting and focusing magnetic fields of the filtered plasma source were not activated. The magnetron discharge was activated by closing magnetron switches 440 to turn on the magnetron power supplies 430. The magnetron current ranged between 2 and 4 amperes. The total gas pressure was increased to 2 mTorr pressure for a gas composition consisting of 20% nitrogen in

argon. The magnetron discharge voltage was 600 V in this pressure range. After the ion cleaning stage the deflecting and focusing coils of the filtered plasma source were activated, the bias voltage was reduced to 80 volts and the deposition process allowed to continue for 10 hours. The thickness of the cBN coating was measured by CALO  
5 test. The hardness of the cBN coating was measured by Knoop microhardness testing equipment at 1g load. The thickness of the cBN coating was found to be  $2 \pm 0.3 \mu\text{m}$ . The Knoop microhardness of the coating was found to be  $55\text{GPa} \pm 5\text{GPa}$ .

#### Example 6

TiN/TiBC two-segment multilayer composite coating. The coating system shown in  
10 Figure 15 was used for the deposition of a two-segment TiN-TiBC multilayer composite coating on the ID and OD surfaces of a steel ring substrate. The first segment of the coating adjacent to the substrate consists of multilayer TiN/Ti coating deposited by a rectangular filtered arc source having both primary rectangular cathodic arc sources equipped with titanium targets. The upper segment consisting of a TiBC  
15 cermet composition was made by co-deposition of titanium from the filtered arc source and boron carbide from both magnetron sources having  $\text{B}_4\text{C}$  targets. For coating the ID surface of the ring, the substrate steel ring was loaded through the back flange of the rectangular filtered arc source in such a way that only a portion of the ring located in front of the filtered arc source exit was exposed to the plasma flow.  
20 The rest of the ring was shielded and not exposed to the coating deposition process. The ring was rotated around its axis providing uniform coverage of the entire ID surface. For deposition of the multilayer TiN/Ti segment, after pre-heating to  $350^\circ\text{C}$  and argon ion cleaning at 250V bias and pressure 0.1Pa, the substrate bias was increased to 1000V and the substrate was treated by titanium ion bombardment for 5  
25 minutes to ensure high coating adhesion. After this stage the argon pressure was reduced to  $3 \times 10^{-2}$  Pa, the bias voltage was reduced to 40 volts and the Ti bond layer was deposited for 5 minutes. After this stage the argon was replaced by nitrogen and the TiN layer was deposited for 25 minutes. The 10 TiN/Ti bilayers were deposited in a similar manner for 5 hours. In the next stage, methane as the second reactive gas was  
30 gradually added to the gas mixture to a 40% concentration. The deposition of the titanium carbonitride interlayer lasted for a further 1 hour. In the next stage, argon as

WO 2005/040451

PCT/US2004/030603

48

sputtering gas was supplied near the magnetron sources. The magnetron sources were turned on and the argon pressure set to  $2 \times 10^{-1}$  Pa, which provided a magnetron voltage in a range between 550 and 600 volts. The magnetron currents were set at 3 amperes each resulting in power density of  $\sim 5.4 \text{ W/cm}^2$ . The substrate temperature provided by the heater array was reduced to  $200^\circ\text{C}$  and 5% of acetylene as a reactive gas was added to the argon. The rectangular filtered arc source continued to work in conjunction with the magnetrons for deposition of the TiBC upper segment composite coating for 5 hours. The resulting dual segment TiN/TiBC coating was found to have the high adhesion (upper critical load  $> 80\text{N}$ ) and a coefficient of friction less than 0.3 against high speed steel. Variations of this type of coatings having high corrosion resistance were obtained by using TiCr or TiZr alloys as targets for the primary cathodic arc sources of the rectangular filtered arc source. For coating the OD surface of the ring, the substrate ring was moved ahead toward the opposite filtered arc-magnetron coating station and coating deposition of the OD surface of the ring was effected using the same coating process as described above for the ID surface.

Preferred embodiments of the invention having been thus described by way of example, modifications and adaptations will be apparent to those skilled in the art. The invention includes all such modifications and adaptations as fall within the scope of the appended claims.

WO 2005/040451

49

PCT/US2004/030603

## I CLAIM:

1. A vacuum arc coating apparatus comprising  
  
at least one rectangular cathode plate having opposed long sides connected to a negative pole of a current source, the at least one cathode plate having a target surface comprising an evaporation surface or a sputtering surface, or both,  
  
a coating chamber in communication with the target surface,  
  
a substrate holder within the coating chamber,  
  
at least one anode spaced from the target surface, connected to a positive pole of a current source, and  
  
a magnetic deflecting system comprising at least first and second conductors arranged along opposite long sides of the at least one cathode plate, the first conductor carrying a current in a direction opposite to a direction of current in the second conductor, the first and second conductors each being disposed in front of and in the vicinity of the target surface so that a magnetic field generated thereby focuses a flow of vapour plasma from the target surface toward the substrate holder, the first conductor being electrically independent of the second steering conductor,  
  
wherein by varying a level of current applied through the first conductor relative to the second conductor the flow of vapor plasma shifts toward the coating chamber.
2. The apparatus of claim 1 further comprising an arc igniter for igniting an arc between the at least one cathode and anode and generating at least one arc spot on the target surface,.

WO 2005/040451

50

PCT/US2004/030603

3. The apparatus of claim 1 wherein the first and second conductors are oriented substantially parallel to the long sides of the cathode plate.
4. The apparatus of claim 3 wherein steering conductors are provided along short sides of the cathode plate.
5. The apparatus of claim 1 wherein the cathode plate is part of an arc source.
6. The apparatus of claim 5 wherein the cathode plate is part of a magnetron source.
7. The apparatus of claim 6 wherein the cathode plate is disposed out of optical alignment with the substrate holder.
8. The apparatus of claim 7 further comprising an ionizer for ionizing the plasma flow.
9. The apparatus of claim 8 wherein focusing conductors are provided along the long sides of the cathode plate to deflect a flow of plasma from the cathode plate to the substrate holder.
10. The apparatus of claim 4 wherein adjacent to one cathode plate are provided a plurality of pairs of steering conductors parallel to the short sides of the one cathode plate and having opposite polarities, to shift arc spots toward a long side of the one cathode plate both at the ends of the one cathode plate.
11. The apparatus of claim 1 wherein each of the plurality of anodes has an associated shield covering an area of the at least one cathode in which arc spots are likely to stagnate.
12. The apparatus of claim 1 further comprising at least one anode surrounding the substrate holder.
13. The apparatus of claim 12 wherein the coating chamber or a portion thereof is grounded to form an anode.

WO 2005/040451

51

PCT/US2004/030603

14. A vacuum arc coating apparatus comprising
- at least one magnetron arc source comprising at least one rectangular cathode plate having opposed long sides, connected to a negative pole of a current source, and sets of magnets disposed behind the at least one cathode plate, the at least one cathode plate having a target surface comprising an evaporation surface or a sputtering surface, or both,
- an anode,
- a coating chamber in communication with the target surface and a housing,
- a substrate holder within the coating chamber,
- a plasma guide disposed between the at least one cathode plate and the coating chamber, the cathode plate being out of optical alignment with the substrate holder, and
- a set of first focusing conductors disposed in front of and generally parallel to the long sides of the at least one cathode plate, for creating a half-cusp configuration of focusing magnetic field lines converging in front of the target surface along the long sides to extract plasma from the arch-shaped magnetron magnetic fields and direct the plasma toward the coating chamber.
15. The apparatus of claim 14 further comprising steering conductors disposed behind and generally parallel to short sides of the at least one cathode plate.
16. The apparatus of claim 15 wherein the magnets are movable away from the at least one cathode plate.
17. The apparatus of claim 16 wherein the magnets are mounted on a magnet plate mounted on a movable shaft.

WO 2005/040451

PCT/US2004/030603

52

18. The apparatus of claim 14 further comprising a high current low voltage arc power supply for supplying a negative voltage to the at least one cathode plate, and an arc igniter, for use of the apparatus in a cathodic arc evaporation mode.
19. The apparatus of claim 14 further comprising a cathode-ionizer out of optical alignment with the anode, for ionizing the plasma.
20. The apparatus of claim 19 wherein the cathode-ionizer is contained within a cathode chamber containing an arc source and a magnetron source is disposed in the coating chamber.
21. The apparatus of claim 19 wherein the cathode-ionizer is contained within the coating chamber and a magnetron source is disposed in a cathode chamber.
22. The apparatus of claim 14 comprising a plurality of cathode plates, wherein a magnetron arc source is associated with each cathode plate.
23. A vacuum arc coating apparatus comprising
- at least one magnetron arc source comprising at least one rectangular cathode plate having opposed long sides, connected to a negative pole of a current source, and sets of magnets disposed behind the at least one cathode plate, the at least one cathode plate having a target surface comprising an evaporation surface or a sputtering surface, or both,
- an anode,
- a coating chamber in communication with the target surface,
- a substrate holder within the coating chamber,
- a plasma guide disposed between the at least one cathode plate and the coating chamber,
- the at least one cathode plate being disposed in the plasma guide, a north pole of the magnetron magnetic field being located at the exit of the filtered arc source and a south pole of the magnetron magnetic field

WO 2005/040451

PCT/US2004/030603

53

being located generally centrally relative to the magnetron, or a south pole of the magnetron magnetic field being located at the exit of the filtered arc source and a north pole of the magnetron magnetic field being located generally centrally relative to the magnetron, whereby magnetic field lines exiting from the filtered arc source reach the evaporation surface,

at least one filtered cathodic arc source out of optical alignment with the substrate holder and adjacent to the at least one magnetron arc source, and

a set of conductors disposed in front of and generally parallel to the long sides of the target surface, for creating focusing magnetic field lines to magnetically couple the magnetron arc source to the filtered arc source and thereby extract plasma from the magnetron and the filtered cathodic arc source and direct the plasma toward the coating chamber.

24. The apparatus of claim 23 comprising a filtered arc source on both sides of the magnetron arc source.

25. The apparatus of claim 23 further comprising steering conductors disposed behind of and generally parallel to short sides of the cathode plate.

26. The apparatus of claim 23 in which the at least one magnetron arc source comprises at least end magnets disposed adjacent to ends of the at least one cathode plate, side magnets disposed adjacent to sides of the at least one cathode plate and a central magnet disposed adjacent to a center of the at least one cathode plate forming a generally rectangular plasma ring between the edge magnets, the central magnet and the end magnets, wherein a magnetron plasma discharge is substantially confined by arch-shaped magnetron magnetic fields in the vicinity of the at least one cathode plate

27. The apparatus of claim 23 further comprising an arc igniter for igniting an arc between the at least one cathode plate and at least one anode to generate arc spots on the evaporation surface.

WO 2005/040451

PCT/US2004/030603

54

28. The apparatus of claim 23 further comprising a cathode-ionizer out of optical alignment with the anode, for ionizing the plasma.

29. The apparatus of claim 28 wherein the cathode-ionizer is contained within a cathode chamber containing an arc source and a magnetron source is disposed in the coating chamber.

30. The apparatus of claim 28 wherein the cathode-ionizer is contained within the coating chamber and a magnetron source is disposed in a cathode chamber.

31. The apparatus of claim 28 wherein the cathode-ionizer comprises a thermionic cathode.

32. The apparatus of claim 28 wherein the cathode-ionizer comprises a hollow cathode.

33. The apparatus of claim 28 wherein the cathode-ionizer comprises a cold vacuum arc cathode.

34. The apparatus of claim 23 wherein the coating chamber or a portion thereof is grounded to form an anode.

35. A method of controlling a flow of plasma in a vacuum arc coating apparatus comprising at least one magnetron arc source comprising at least one rectangular cathode plate having opposed long sides and connected to a negative pole of a current source and having a target surface comprising an evaporation surface or a sputtering surface, or both, an anode, and a coating chamber in communication with the target surface containing a substrate holder comprising the steps of:

a. generating at least one cathode spot on the target surface to create a plasma, and

b. generating a deflecting magnetic field having deflecting magnetic field lines overlapping with magnetron magnetic field lines generated by the magnetron, the deflecting magnetic field lines and the magnetron magnetic field lines having the same transverse direction,

WO 2005/040451

55

PCT/US2004/030603

whereby the deflecting magnetic field draws plasma from the magnetron magnetic field and deflects the plasma toward the coating chamber.

36. The method of claim 35 wherein the deflecting magnetic field is generated by deflecting conductors disposed in front of and generally parallel to the long sides of the target surface.

37. The method of claim 36 wherein a current through the deflecting conductors on opposite sides of the target surface can be controlled independently.

38. The method of claim 37 comprising the step of c. alternately varying a level of current through the deflecting conductors on opposite sides of the target surface to raster the flow of plasma.

39. The method of claim 36 wherein the deflecting conductors are disposed immediately in front of the target surface such that the magnetic field lines in front of the conductors overlap the magnetron magnetic field lines to thereby draw plasma away from the center of the arc source.

40. The method of claim 39 wherein the deflecting conductors are also disposed adjacent to a filtered arc source, to magnetically couple the arc source and the filtered arc source and simultaneously deflect a flow of plasma from both the magnetron arc source and the filtered arc source toward the coating chamber.

41. The method of claim 36 wherein the deflecting conductors are disposed in front of the target surface and spaced from the target surface such that the magnetic field lines in rearward of the conductors overlap the magnetron magnetic field lines to thereby draw plasma toward the center of the arc source.

42. The method of claim 41 wherein the arc source is disposed out of optical alignment with the substrate holder.

43. The method of claim 36 wherein the coating chamber or a portion thereof is grounded to form an anode.

WO 2005/040451

PCT/US2004/030603

56

44. The method of claim 36 comprising, before step a., the step of loading substrates in a vertical arrangement in the plasma guide, and during steps a. and b., rotating the substrates.

WO 2005/040451

PCT/US2004/030603

57

## AMENDED CLAIMS

[Received by the International Bureau on 16 February 2005 (16.02.2005):  
original claims 1-35 replaced by amended claims 1-44]

## I CLAIM:

1. A vacuum arc coating apparatus comprising  
  
at least one rectangular cathode plate having opposed long sides connected to a negative pole of a current source, the at least one cathode plate having a target surface comprising an evaporation surface or a sputtering surface, or both,  
  
a coating chamber in communication with the target surface,  
  
a substrate holder within the coating chamber,  
  
at least one anode spaced from the target surface, connected to a positive pole of a current source, and  
  
a magnetic deflecting system comprising at least first and second conductors arranged along opposite long sides of the at least one cathode plate, the first conductor carrying a current in a direction opposite to a direction of current in the second conductor, the first and second conductors each being disposed in front of and in the vicinity of the target surface so that a magnetic field generated thereby focuses a flow of vapour plasma from the target surface toward the substrate holder, the first conductor being electrically independent of the second steering conductor,  
  
wherein by varying a level of current applied through the first conductor relative to the second conductor the flow of vapor plasma shifts toward the coating chamber.
2. The apparatus of claim 1 further comprising an arc igniter for igniting an arc between the at least one cathode and anode and generating at least one arc spot on the target surface.

AMENDED SHEET (ARTICLE 19)

WO 2005/040451

58

PCT/US2004/030603

3. The apparatus of claim 1 wherein the first and second conductors are oriented substantially parallel to the long sides of the at least one cathode plate.
4. The apparatus of claim 3 wherein steering conductors are provided along short sides of each of the at least one cathode plates.
5. The apparatus of claim 1 wherein the cathode plate is part of an arc source.
6. The apparatus of claim 5 wherein the cathode plate is part of a magnetron source.
7. The apparatus of claim 6 wherein the cathode plate is disposed out of optical alignment with the substrate holder.
8. The apparatus of claim 7 further comprising an ionizer for ionizing the plasma flow.
9. The apparatus of claim 8 wherein focusing conductors are provided along the long sides of the cathode plate to deflect a flow of plasma from the cathode plate to the substrate holder.
10. The apparatus of claim 4 wherein adjacent to each of said at least one cathode plates are provided a plurality of pairs of steering conductors parallel to the short sides of each of said at least one cathode plates and having opposite polarities, to shift arc spots toward a long side of each of said at least one cathode plates both at the ends of the one cathode plate.
11. The apparatus of claim 1 wherein each of said at least one anode has an associated shield covering an area of the at least one cathode in which arc spots are likely to stagnate.
12. The apparatus of claim 1 further comprising at least one anode surrounding the substrate holder.
13. The apparatus of claim 12 wherein the coating chamber or a portion thereof is grounded to form an anode.

AMENDED SHEET (ARTICLE 19)

WO 2005/040451

PCT/US2004/030603

59

14. A vacuum arc coating apparatus comprising
- at least one magnetron arc source comprising at least one rectangular cathode plate having opposed long sides, connected to a negative pole of a current source, and sets of magnets disposed behind the at least one cathode plate, the at least one cathode plate having a target surface comprising an evaporation surface or a sputtering surface, or both, wherein said at least one magnetron arc source creates an arch-shaped magnetic field having magnetic field lines projecting above said target surface,
- an anode,
- a coating chamber in communication with the target surface and a housing,
- a substrate holder within the coating chamber,
- a plasma guide disposed between the at least one cathode plate and the coating chamber, the cathode plate being out of optical alignment with the substrate holder, and
- a set of first focusing conductors disposed in front of and generally parallel to the long sides of the at least one cathode plate, for creating a half-cusp configuration of focusing magnetic field lines converging in front of the target surface along the long sides to extract plasma from the arch-shaped magnetron magnetic fields and direct the plasma toward the coating chamber.
15. The apparatus of claim 14 further comprising steering conductors disposed behind and generally parallel to short sides of the at least one cathode plate,
16. The apparatus of claim 15 wherein the sets of magnets are movable away from the at least one cathode plate,
17. The apparatus of claim 16 wherein the sets of magnets are mounted on a magnet plate mounted on a movable shaft,

AMENDED SHEET (ARTICLE 19)

WO 2005/040451

60

PCT/US2004/030603

18. The apparatus of claim 14 further comprising a high current low voltage arc power supply for supplying a negative voltage to the at least one cathode plate, and an arc igniter, for use of the apparatus in a cathodic arc evaporation mode.
19. The apparatus of claim 14 further comprising a cathode-ionizer out of optical alignment with the anode, for ionizing the plasma.
20. The apparatus of claim 19 wherein the cathode-ionizer is contained within a cathode chamber containing an arc source and a magnetron source is disposed in the coating chamber.
21. The apparatus of claim 19 wherein the cathode-ionizer is contained within the coating chamber and a magnetron source is disposed in a cathode chamber.
22. The apparatus of claim 14 comprising a plurality of cathode plates, wherein a magnetron arc source is associated with each cathode plate.
23. A vacuum arc coating apparatus comprising  
at least one magnetron arc source comprising at least one rectangular cathode plate having opposed long sides, connected to a negative pole of a current source, and sets of magnets disposed behind the at least one cathode plate, the at least one cathode plate having a target surface comprising an evaporation surface or a sputtering surface, or both, wherein said at least one magnetron arc source creates a magnetron magnetic field having magnetic field lines projecting above said target surface,  
an anode,  
a coating chamber in communication with the target surface,  
a substrate holder within the coating chamber,  
a plasma guide disposed between the at least one cathode plate and the coating chamber,  
at least one filtered cathodic arc source out of optical alignment with the substrate holder and adjacent to the at least one magnetron arc source, the at least one cathode plate being disposed in the plasma guide, a north pole of the magnetron magnetic field being located at the exit of the filtered arc source and a south pole of the magnetron magnetic field

AMENDED SHEET (ARTICLE 19)

WO 2005/040451

PCT/US2004/030603

61

being located generally centrally relative to the magnetron, or a south pole of the magnetron magnetic field being located at the exit of the filtered arc source and a north pole of the magnetron magnetic field being located generally centrally relative to the magnetron, whereby magnetic field lines exiting from the filtered arc source reach the evaporation surface,

and

a set of conductors disposed in front of and generally parallel to the long sides of the target surface, for creating focusing magnetic field lines to magnetically couple the magnetron arc source to the filtered arc source and thereby extract plasma from the magnetron and the filtered cathodic arc source and direct the plasma toward the coating chamber.

24. The apparatus of claim 23 comprising a filtered arc source on both sides of said at least one magnetron arc source.
25. The apparatus of claim 23 further comprising steering conductors disposed behind of and generally parallel to short sides of said at least one cathode plate.
26. The apparatus of claim 23 in which the at least one magnetron arc source comprises at least end magnets disposed adjacent to ends of the at least one cathode plate, side magnets disposed adjacent to sides of the at least one cathode plate and a central magnet disposed adjacent to a center of the at least one cathode plate forming a generally rectangular plasma ring between the edge magnets, the central magnet and the end magnets, wherein a magnetron plasma discharge is substantially confined by arch-shaped magnetron magnetic fields in the vicinity of the at least one cathode plate
27. The apparatus of claim 23 further comprising an arc igniter for igniting an arc between the at least one cathode plate and at least one anode to generate arc spots on the evaporation surface.

AMENDED SHEET (ARTICLE 19)

WO 2005/040451

PCT/US2004/030603

62

28. The apparatus of claim 23 further comprising a cathode-ionizer out of optical alignment with the anode, for ionizing the plasma.

29. The apparatus of claim 28 wherein the cathode-ionizer is contained within a cathode chamber containing an arc source and a magnetron source is disposed in the coating chamber,

30. The apparatus of claim 28 wherein the cathode-ionizer is contained within the coating chamber and a magnetron source is disposed in a cathode chamber.

31. The apparatus of claim 28 wherein the cathode-ionizer comprises a thermionic cathode.

32. The apparatus of claim 28 wherein the cathode-ionizer comprises a hollow cathode.

33. The apparatus of claim 28 wherein the cathode-ionizer comprises a cold vacuum arc cathode.

34. The apparatus of claim 23 wherein the coating chamber or a portion thereof is grounded to form an anode.

35. A method of controlling a flow of plasma in a vacuum arc coating apparatus comprising at least one magnetron arc source comprising at least one rectangular cathode plate having opposed long sides and connected to a negative pole of a current source and having a target surface comprising an evaporation surface or a sputtering surface, or both, an anode, and a coating chamber in communication with the target surface containing a substrate holder comprising the steps of:

a. generating at least one cathode spot on the target surface to create a plasma, and

b. generating a deflecting magnetic field having deflecting magnetic field lines overlapping with magnetron magnetic field lines generated by said at least one magnetron arc source, the deflecting magnetic field lines and the magnetron magnetic field lines having the same transverse direction,

AMENDED SHEET (ARTICLE 19)

WO 2005/040451

PCT/US2004/030603

1/26

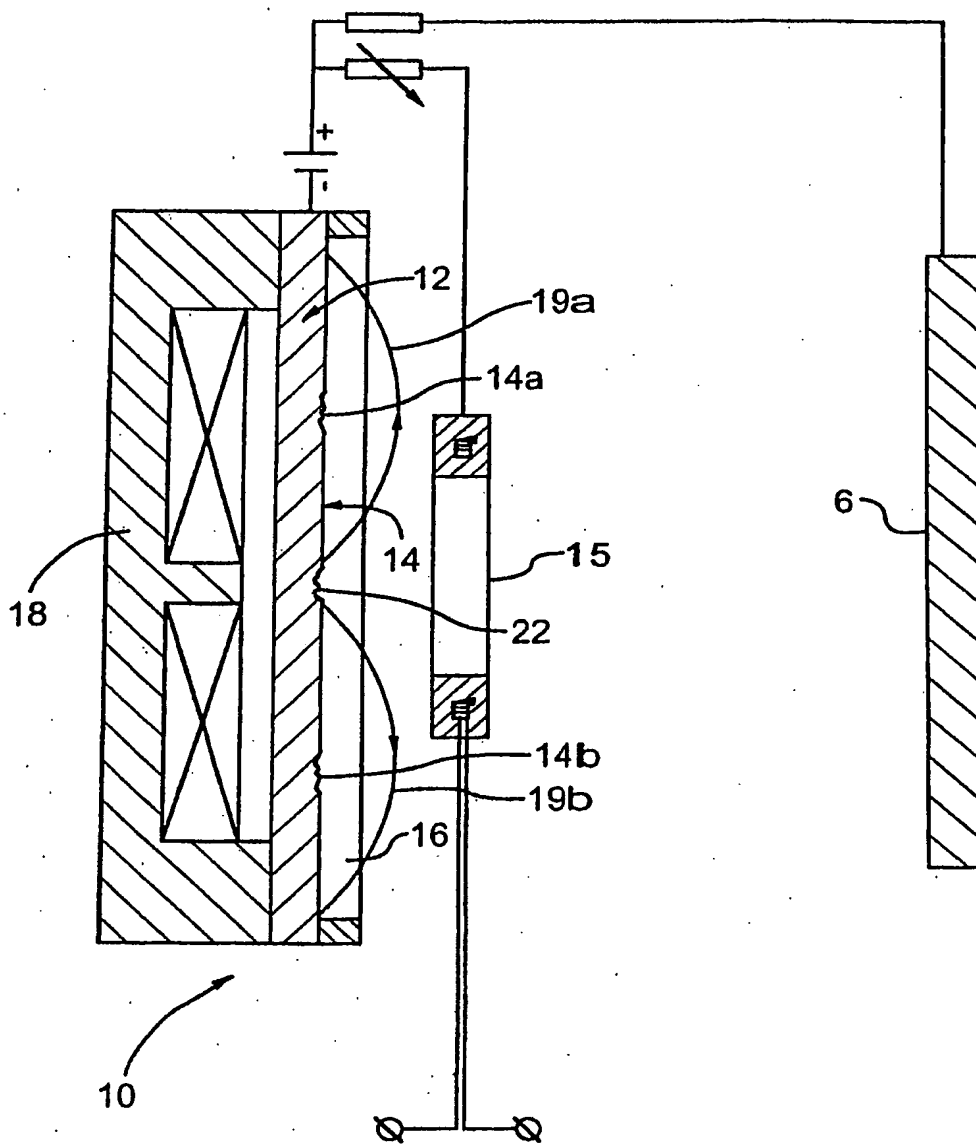


FIG.1

WO 2005/040451

PCT/US2004/030603

2/26

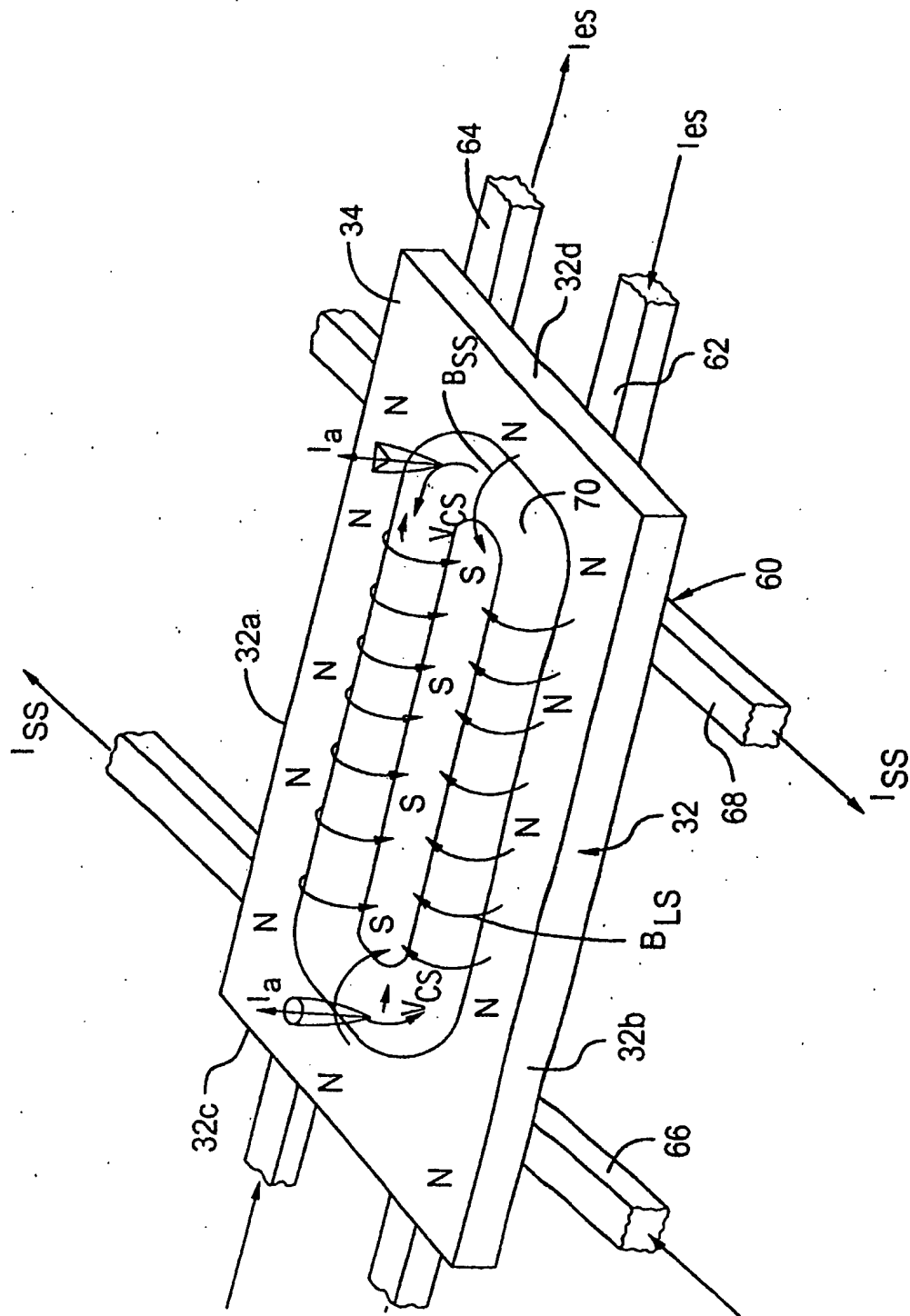


FIG. 2

WO 2005/040451

PCT/US2004/030603

3/26

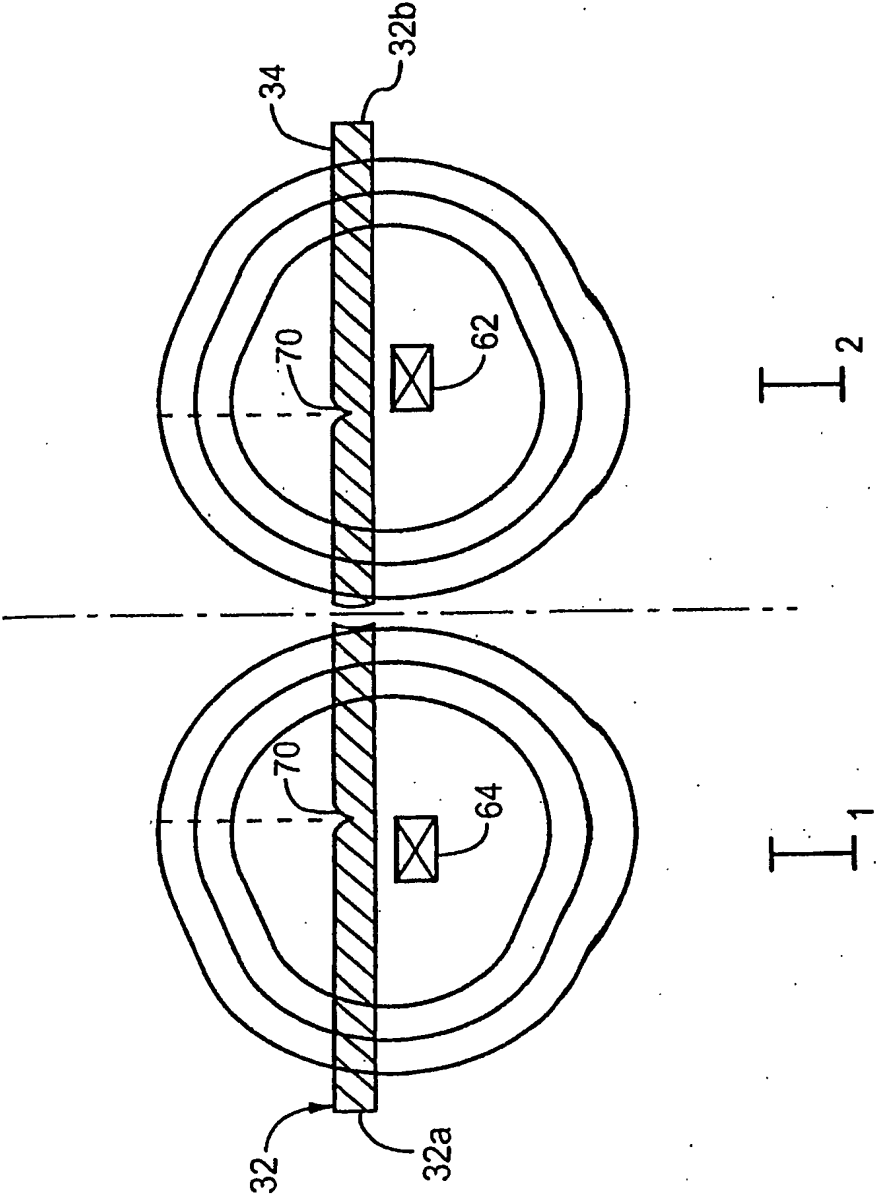
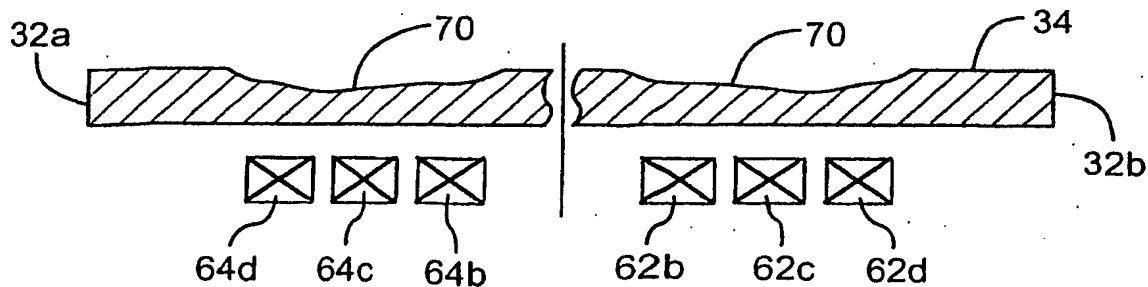
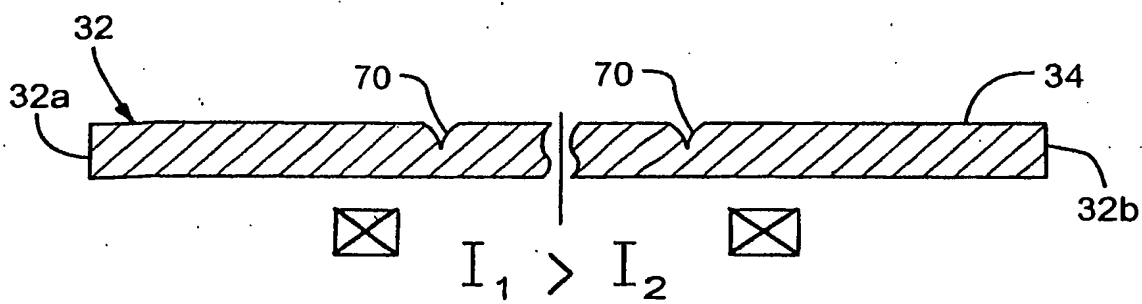
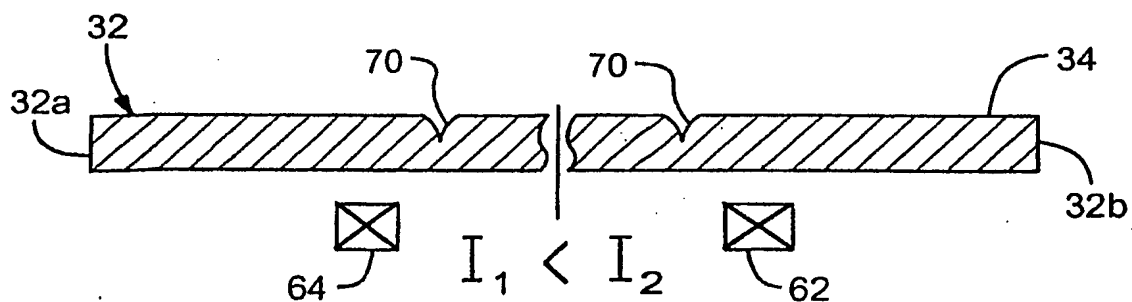


FIG. 2a

WO 2005/040451

PCT/US2004/030603

4/26



WO 2005/040451

PCT/US2004/030603

5/26

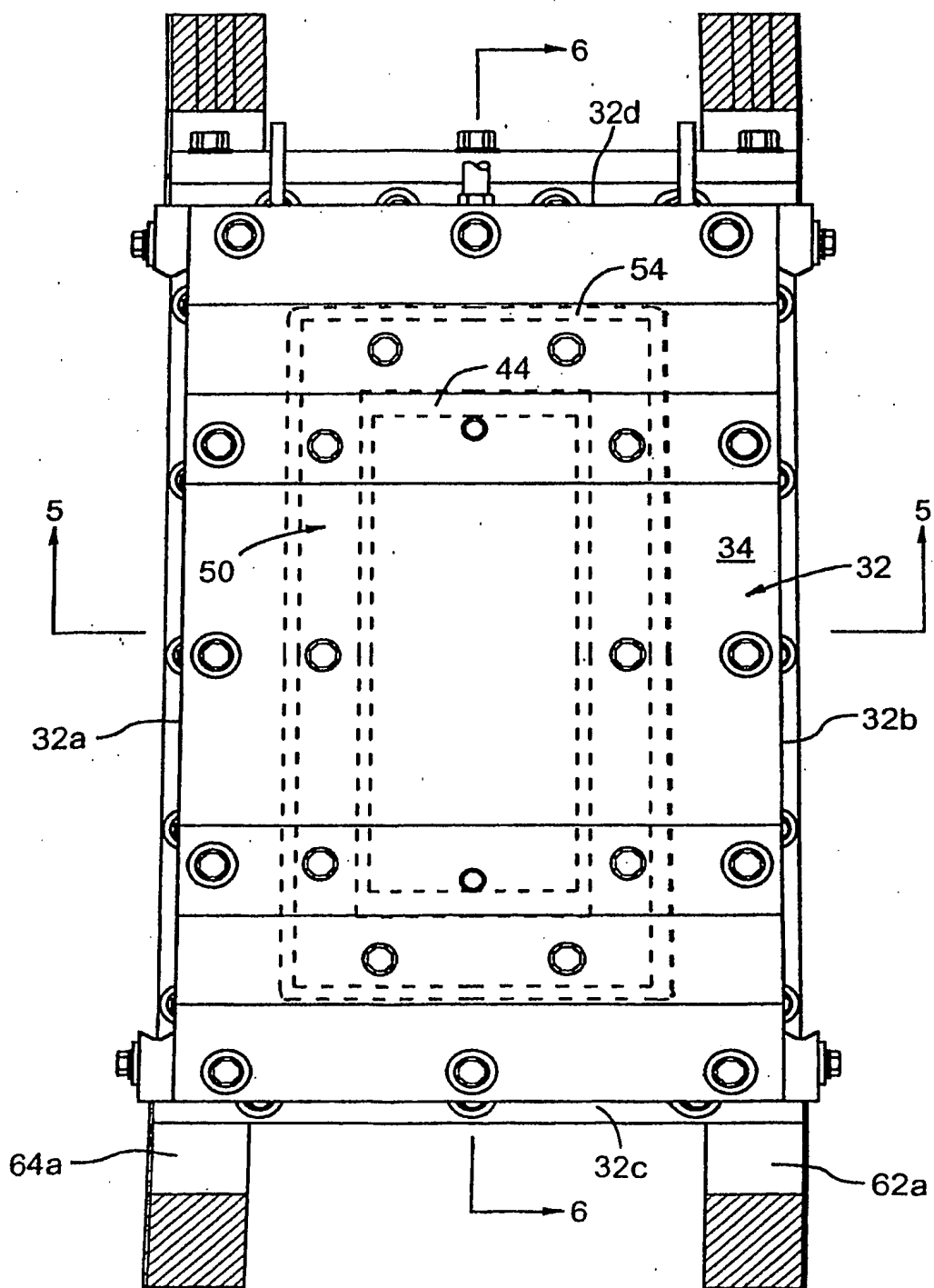


FIG. 4

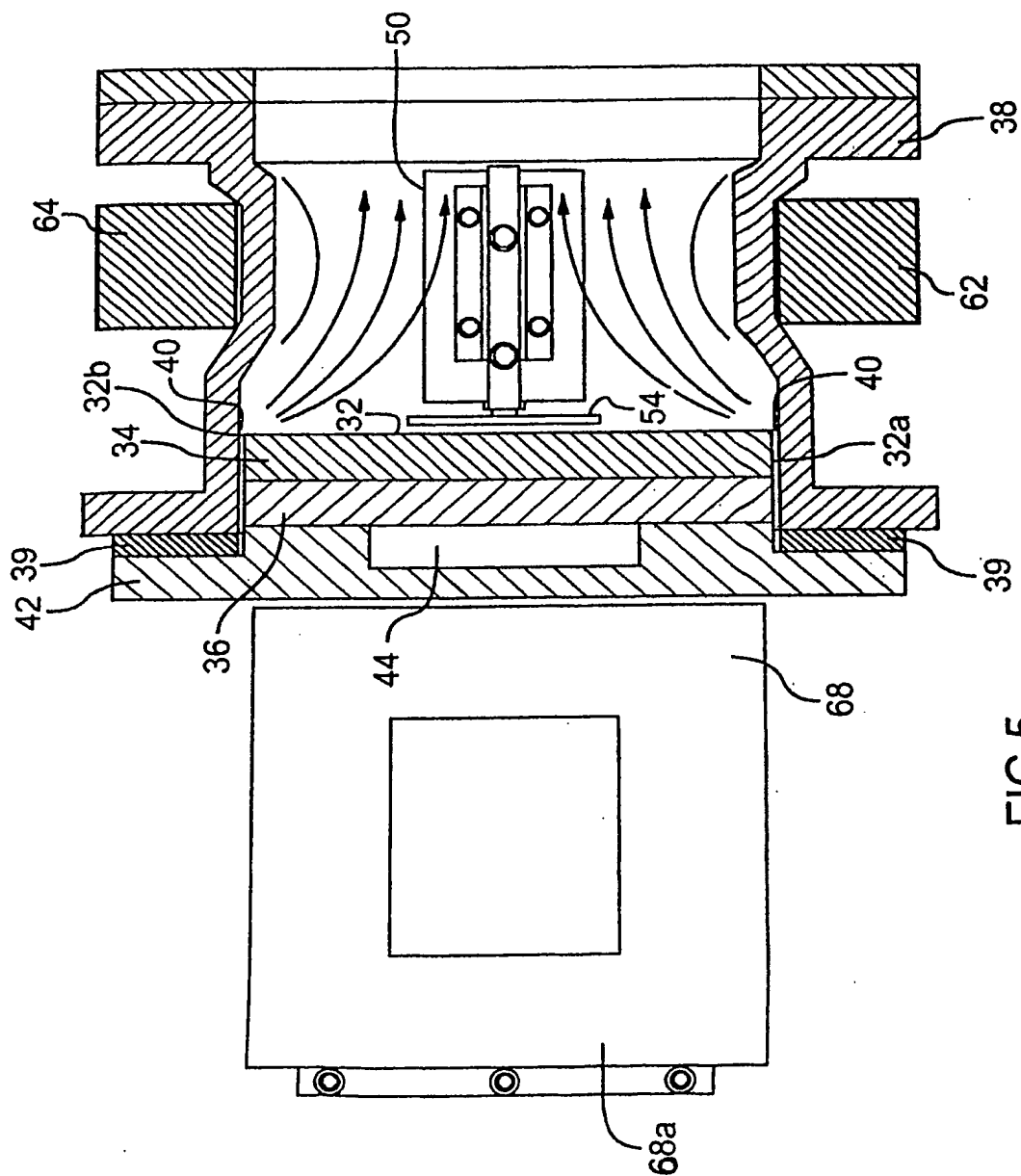


FIG. 5

WO 2005/040451

PCT/US2004/030603

7/26

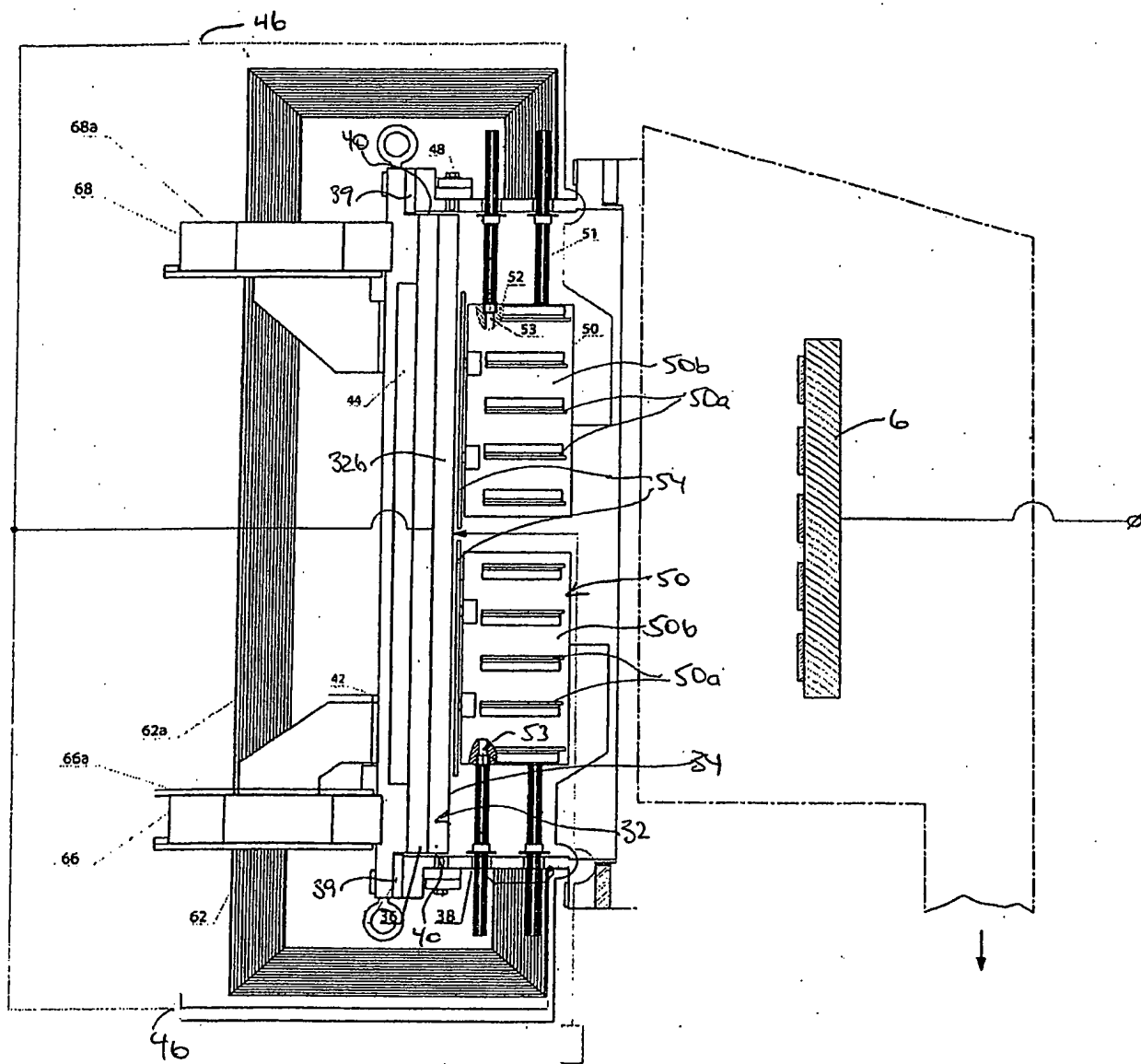


Fig. 6a

WO 2005/040451

PCT/US2004/030603

8/26

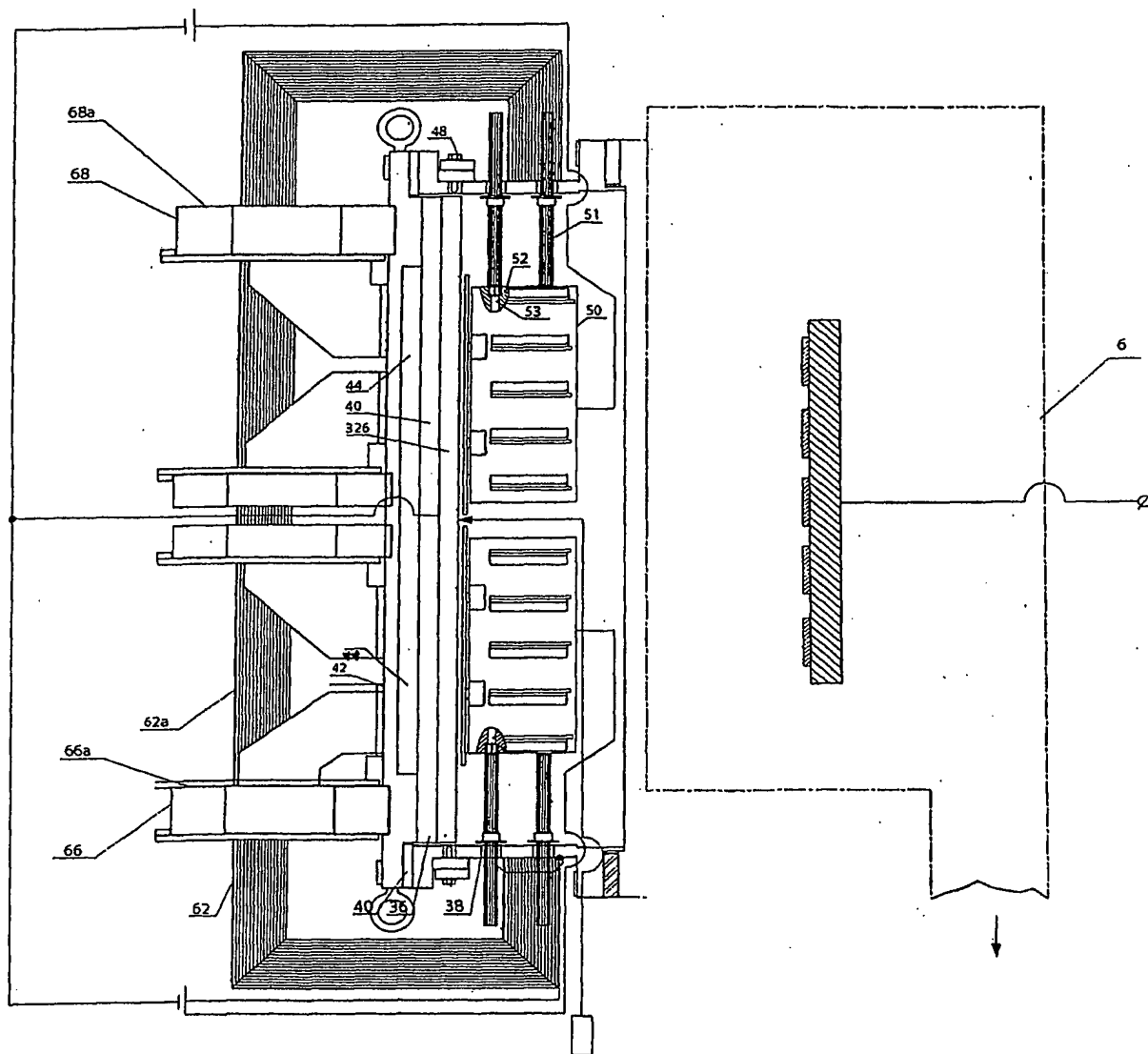


Fig. 6b

WO 2005/040451

PCT/US2004/030603

9/26

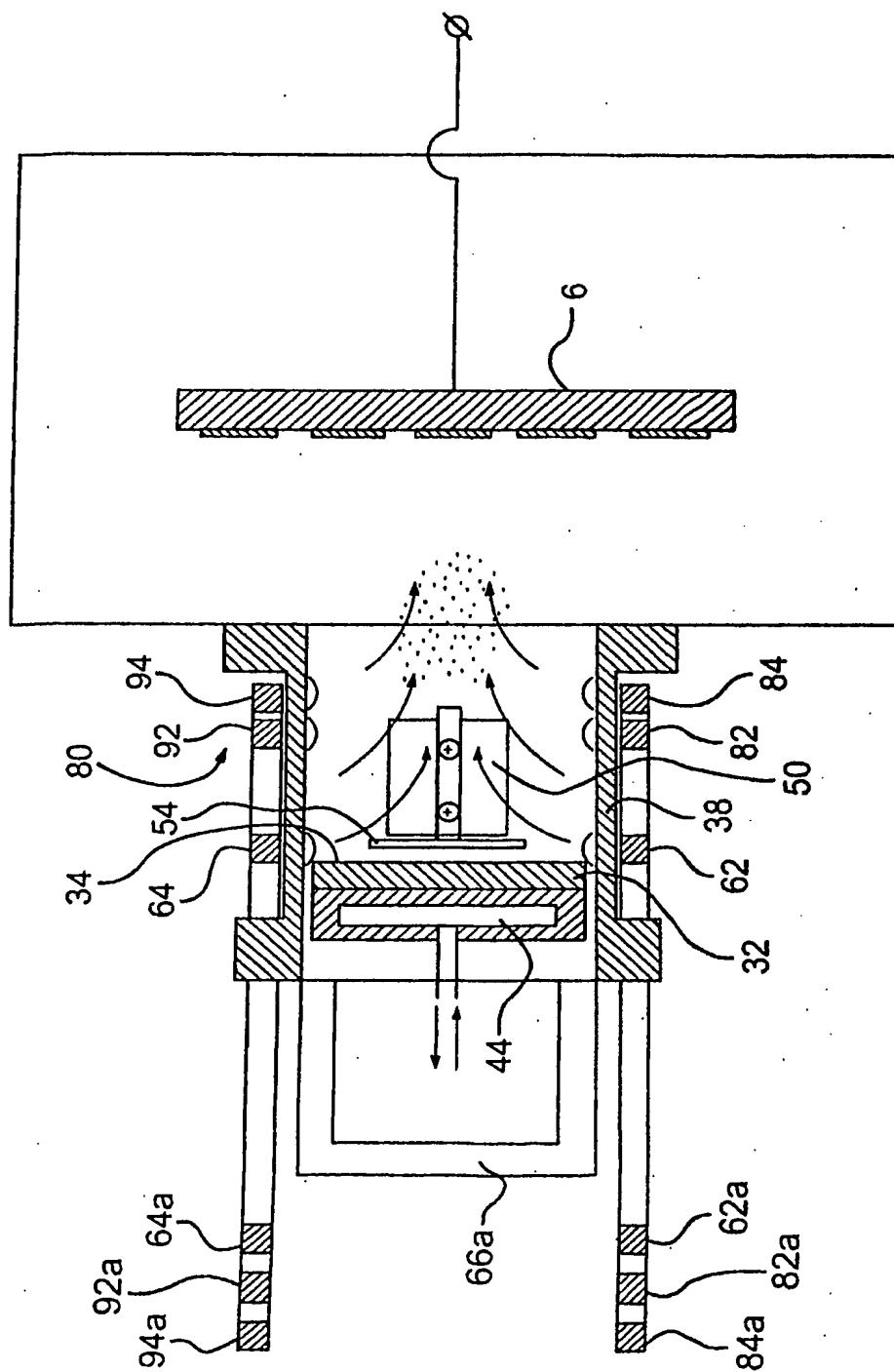


FIG.7a

10/26

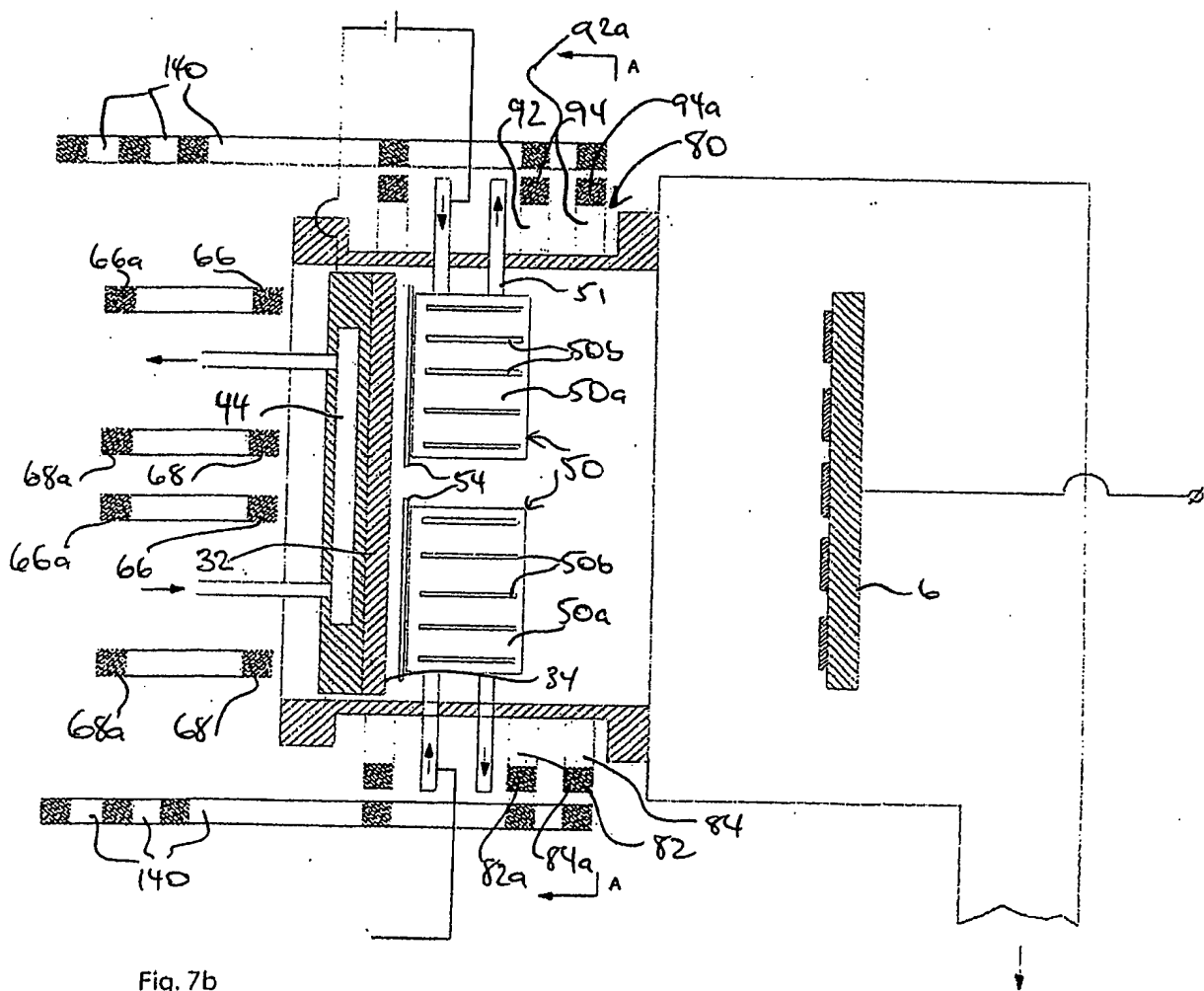


Fig. 7b

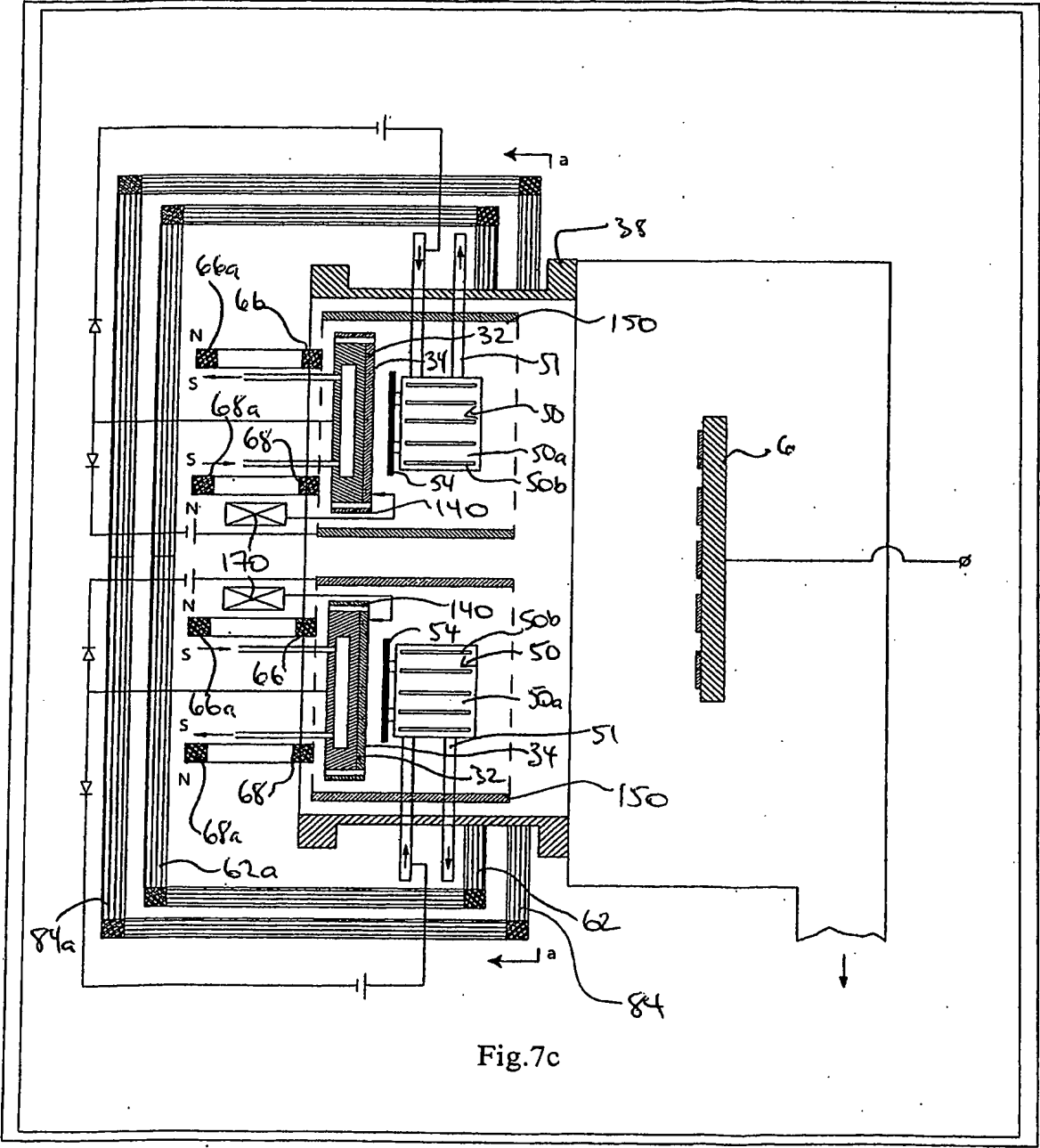
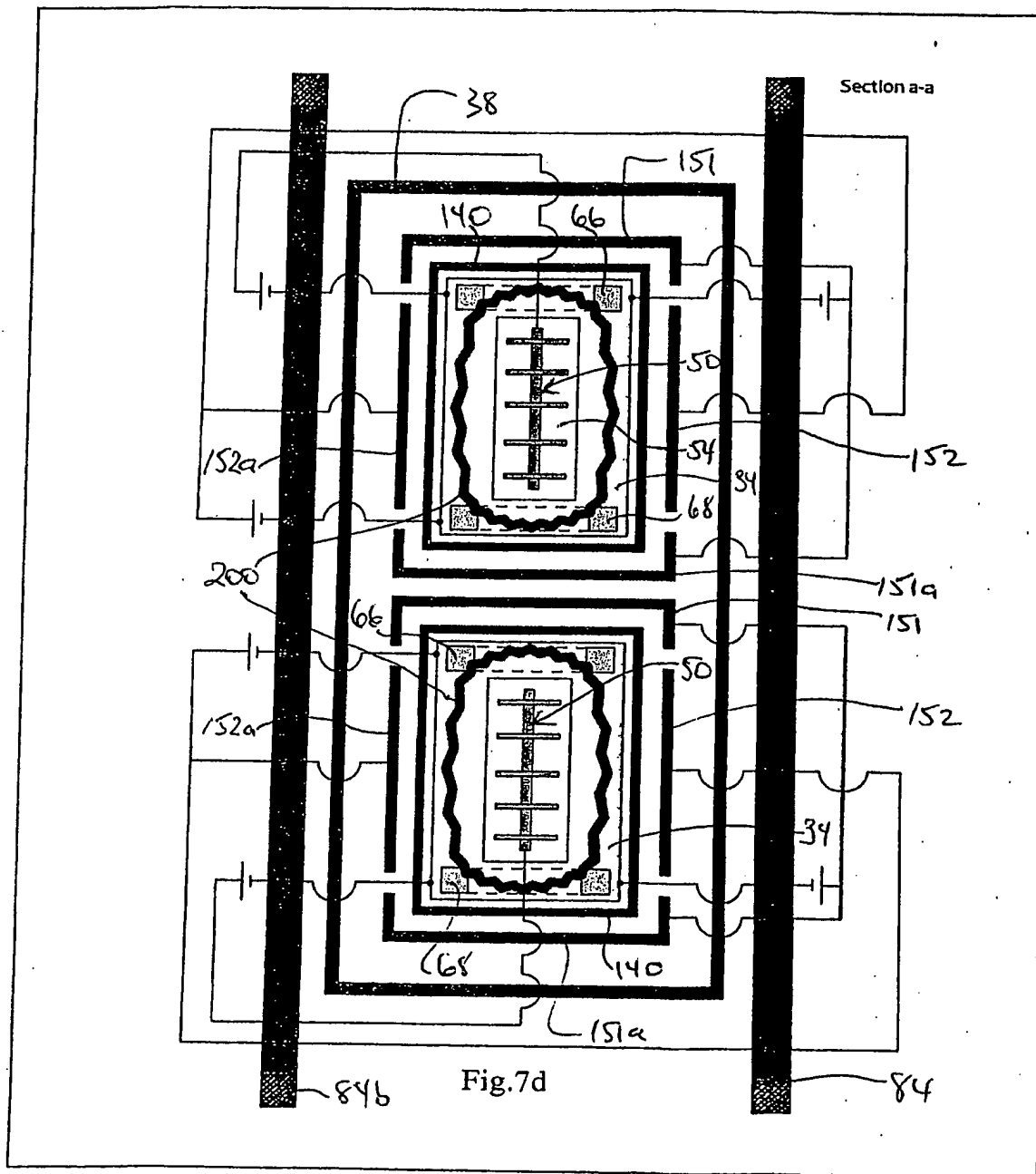


Fig. 7c

WO 2005/040451

PCT/US2004/030603

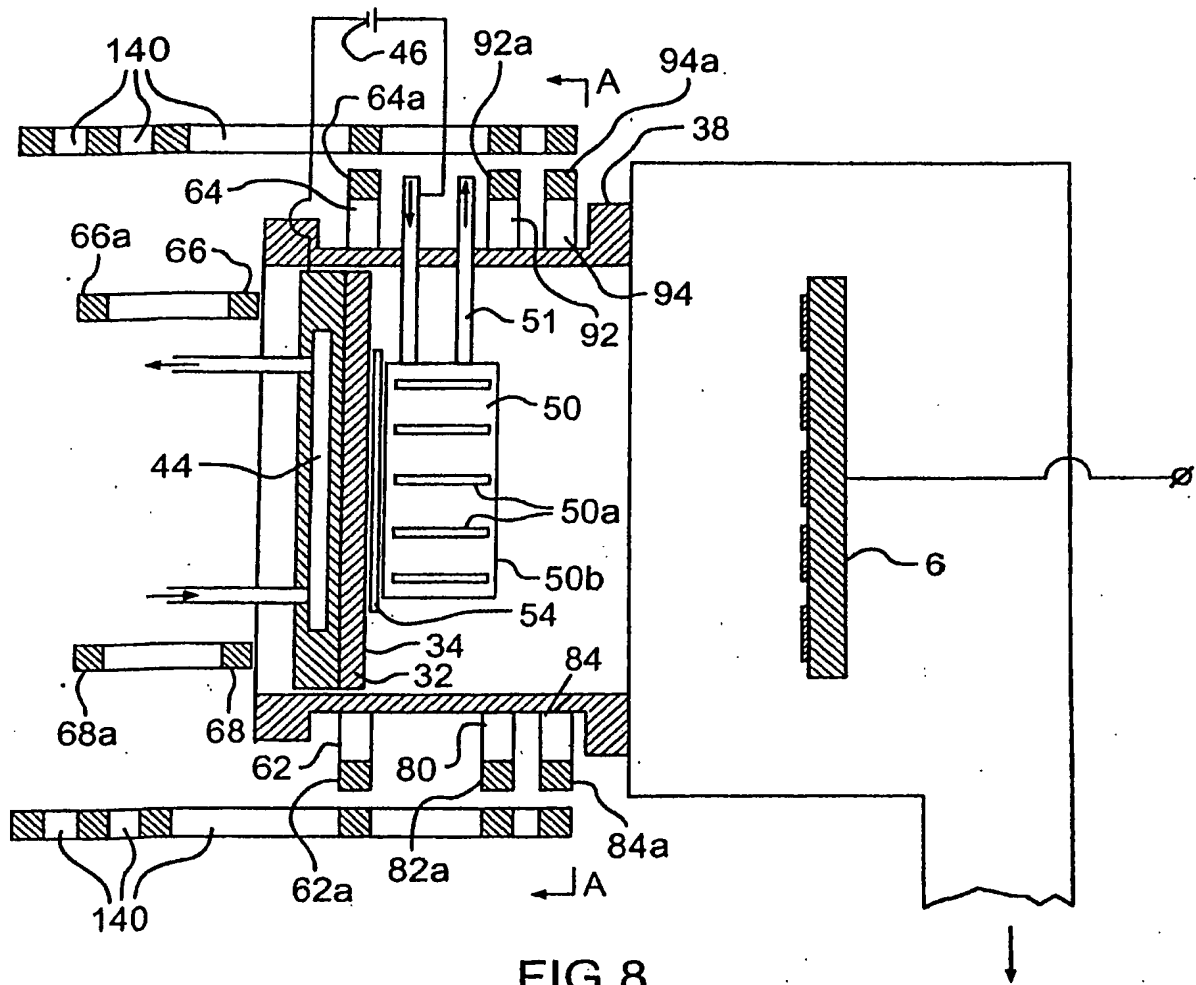
12/26



WO 2005/040451

PCT/US2004/030603

13/26



WO 2005/040451

PCT/US2004/030603

14/26

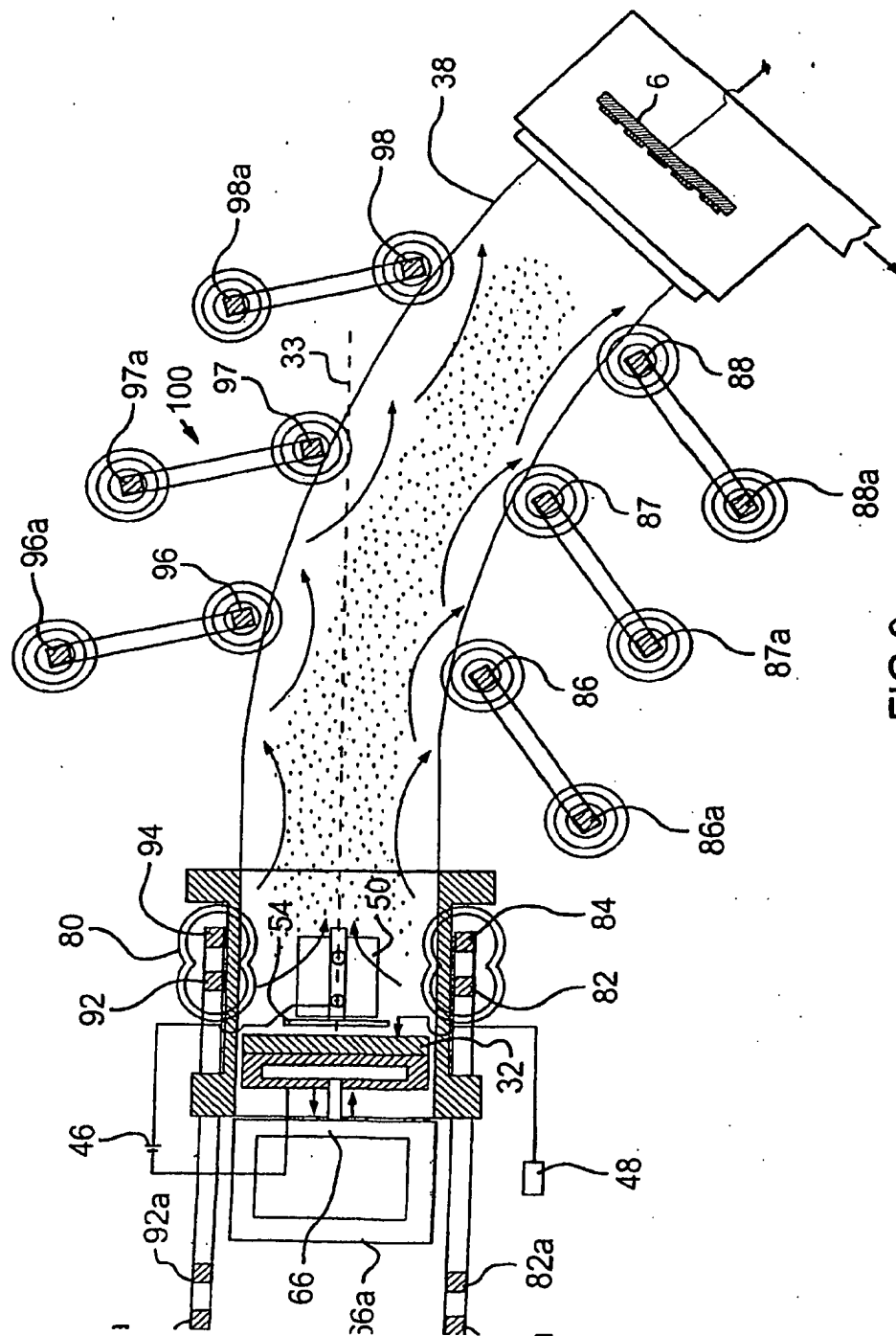


FIG. 9

WO 2005/040451

PCT/US2004/030603

15/26

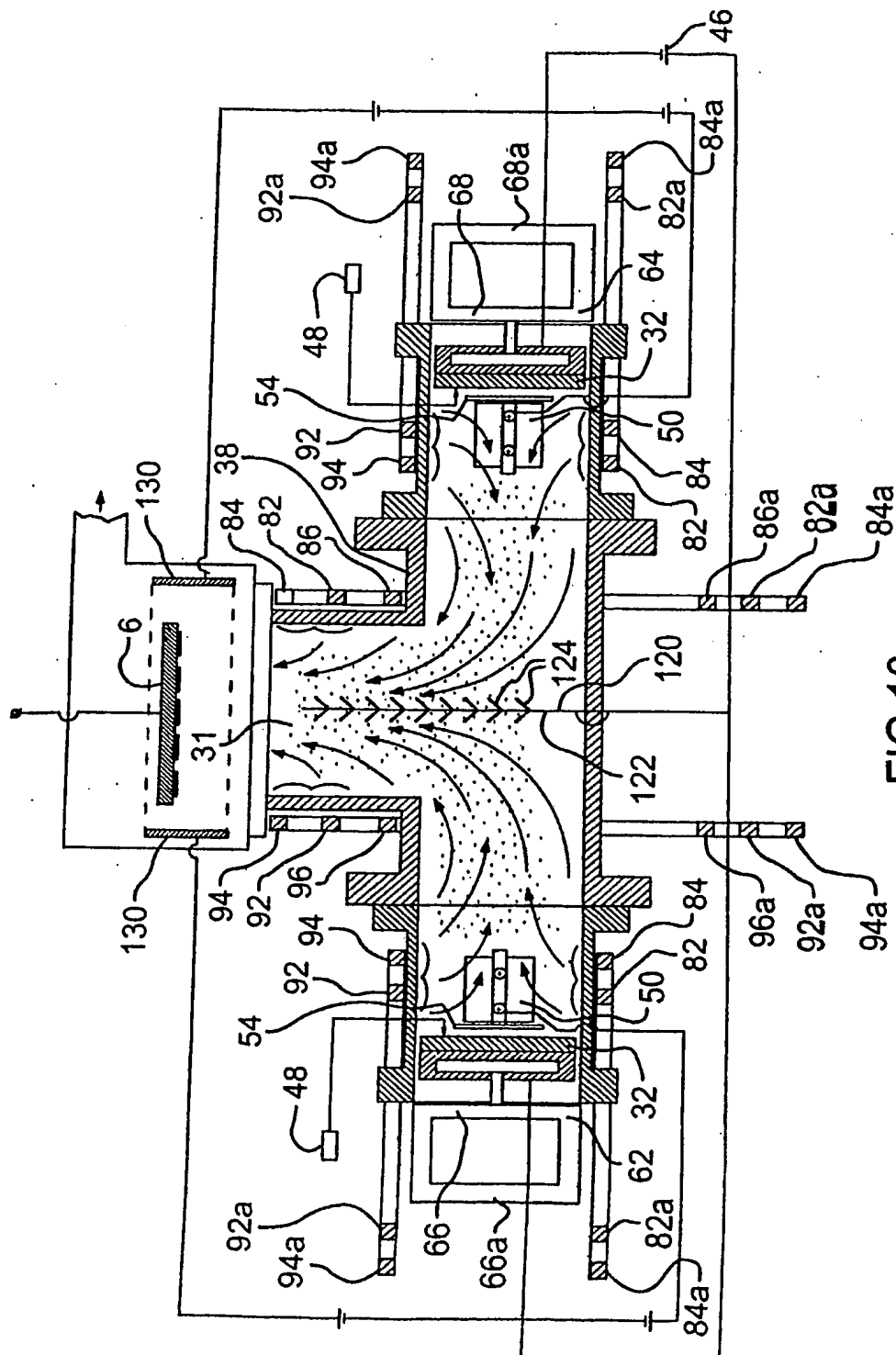


FIG. 10a

WO 2005/040451

PCT/US2004/030603

16/26

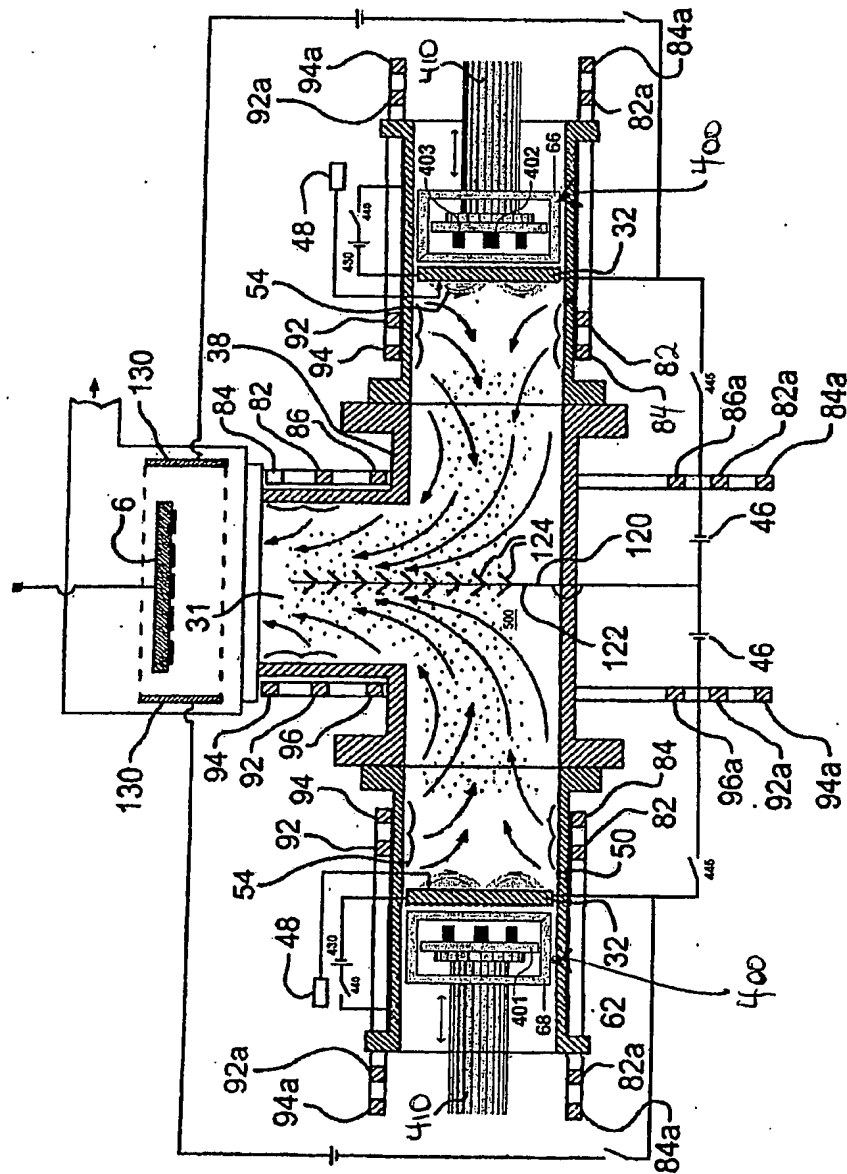


Fig. 10b

WO 2005/040451

PCT/US2004/030603

17/26

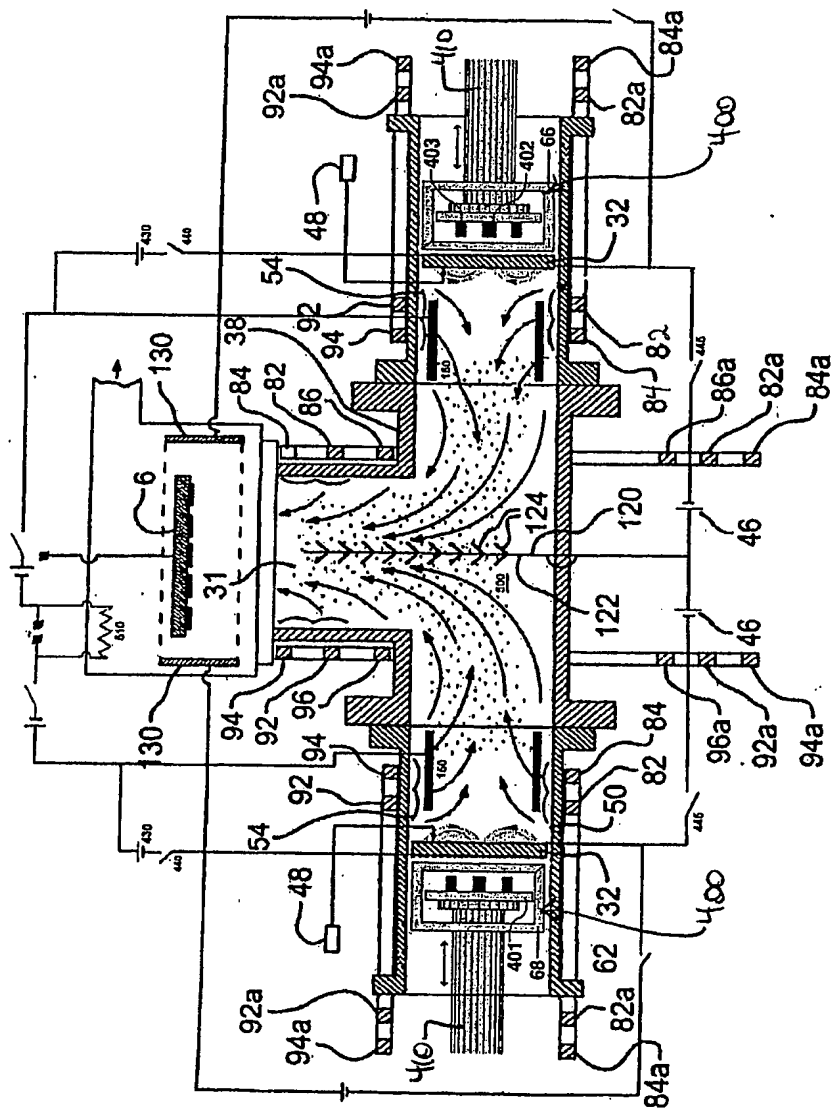


Fig. 10c

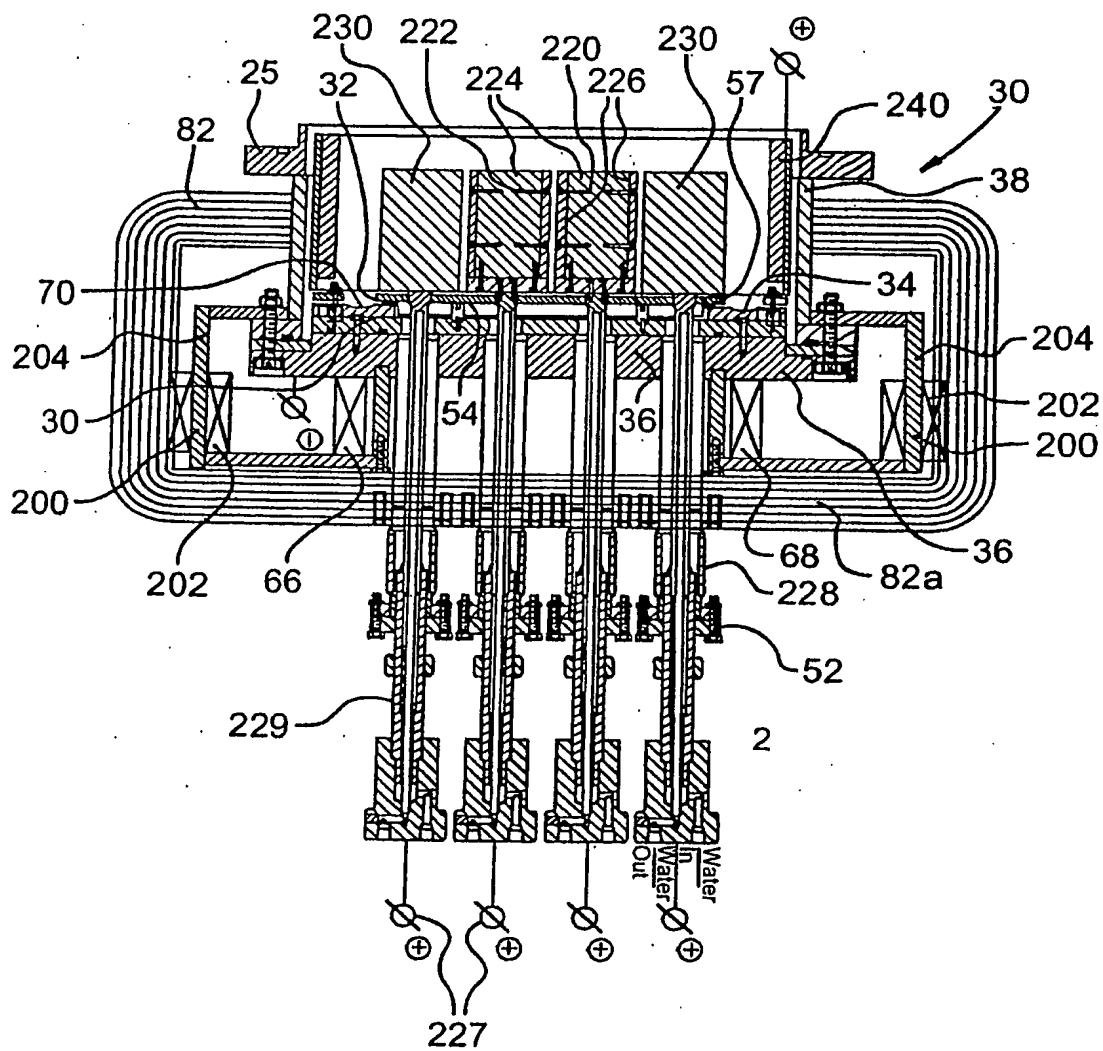


FIG. 11

WO 2005/040451

PCT/US2004/030603

19/26

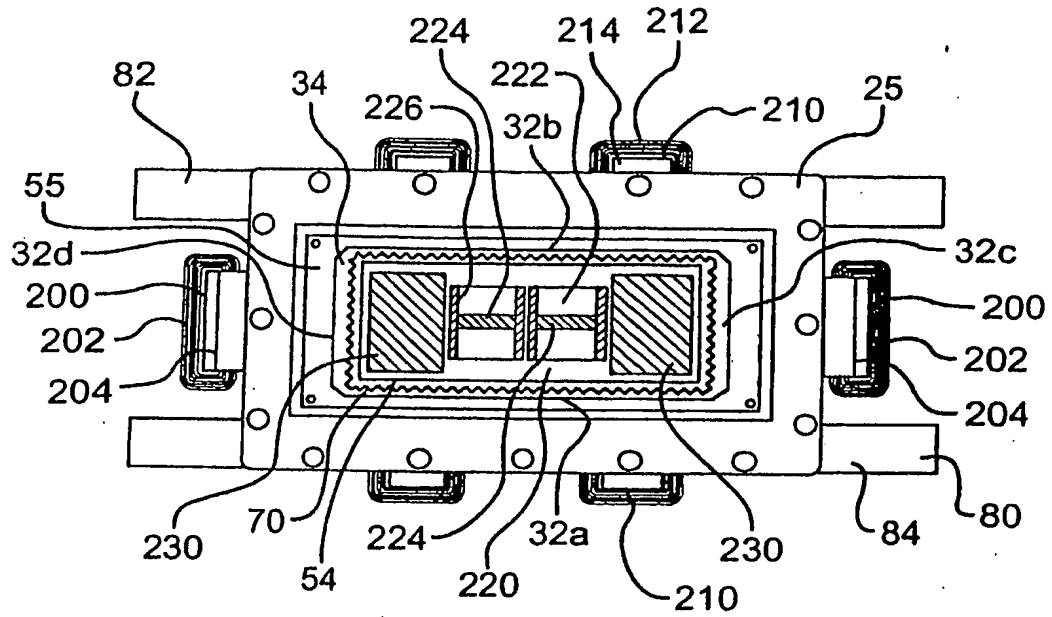


FIG. 12

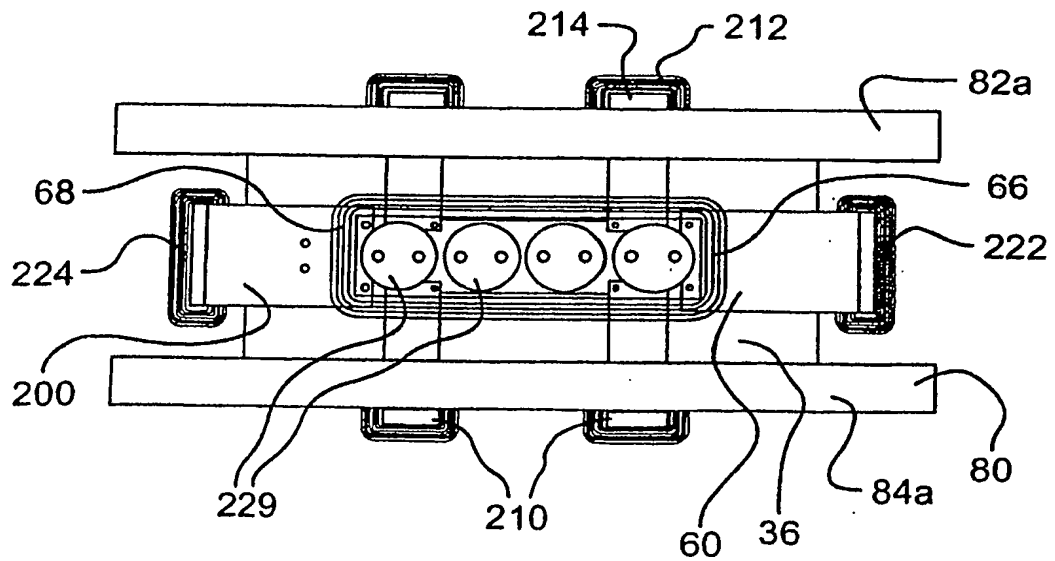


FIG. 13

WO 2005/040451

PCT/US2004/030603

20/26

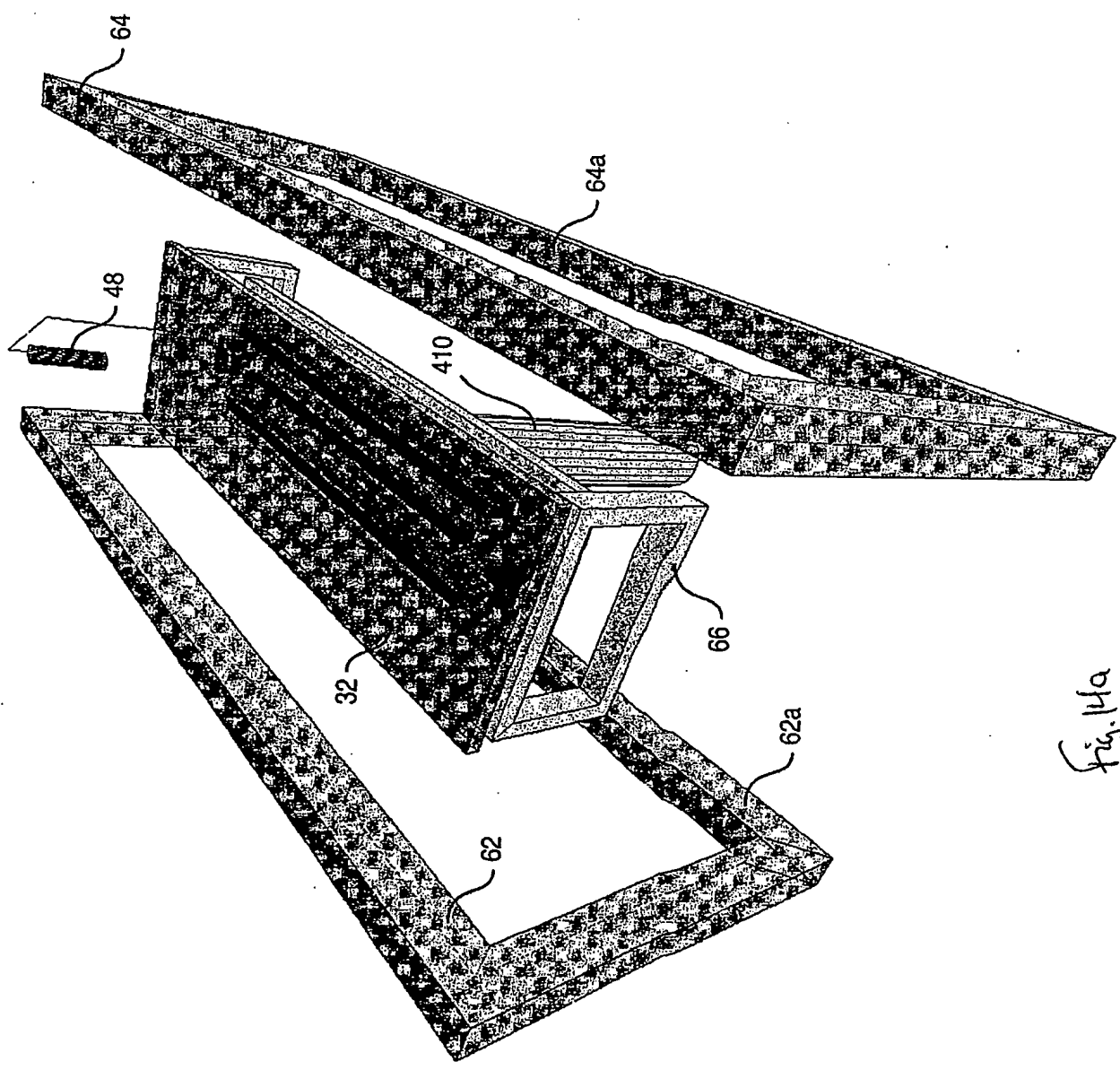


Fig. 14a

WO 2005/040451

PCT/US2004/030603

21/26

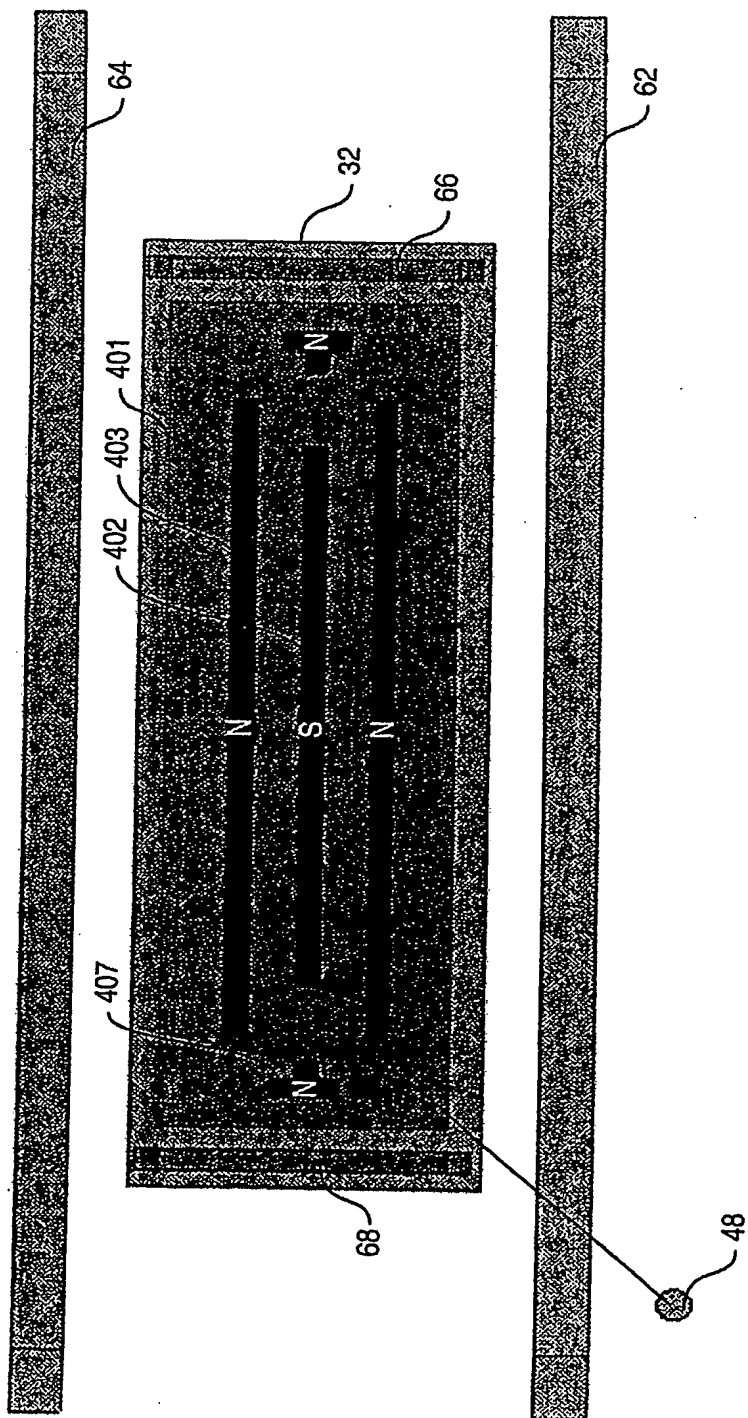


Fig. 44b

WO 2005/040451

PCT/US2004/030603

22/26

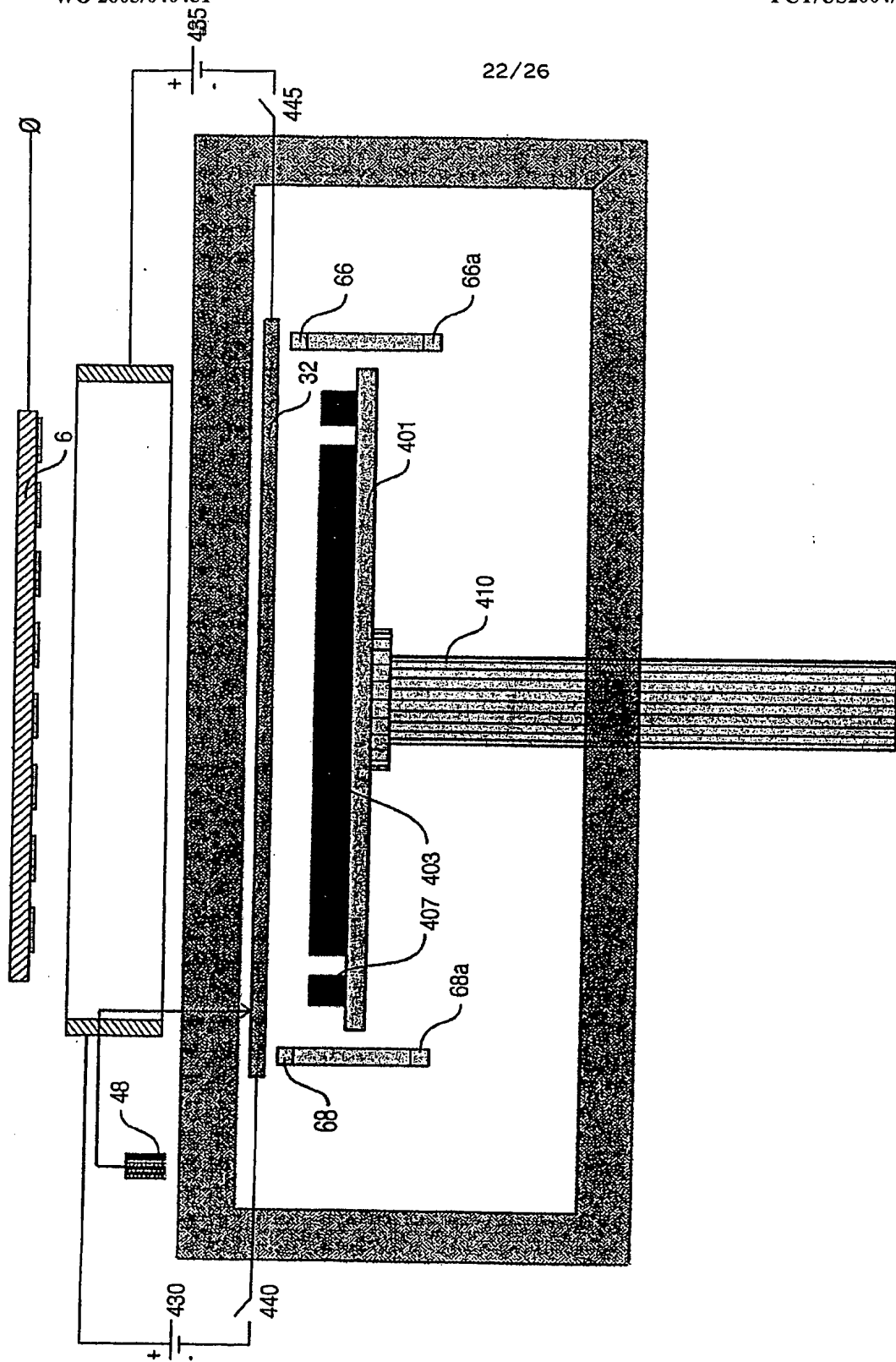


Fig. 14c

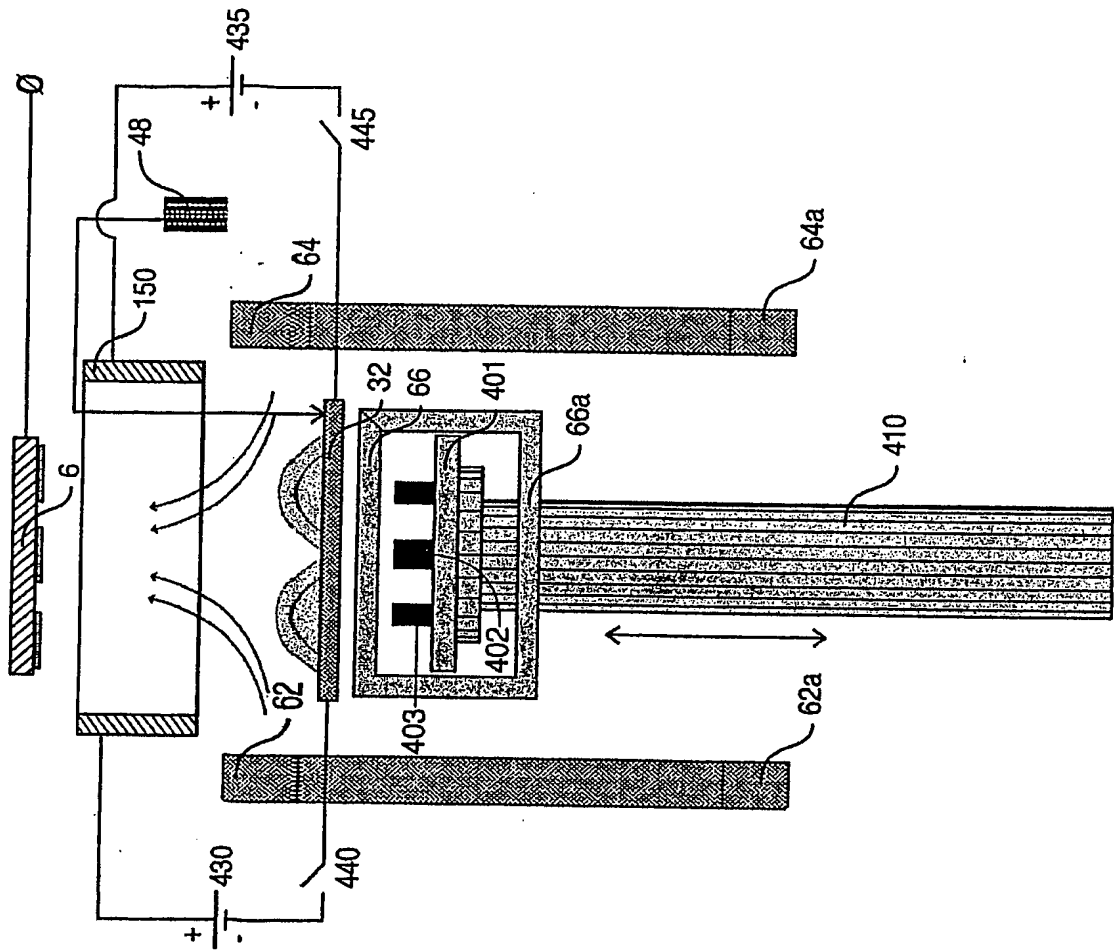


Fig. 14d

WO 2005/040451

PCT/US2004/030603

24/26

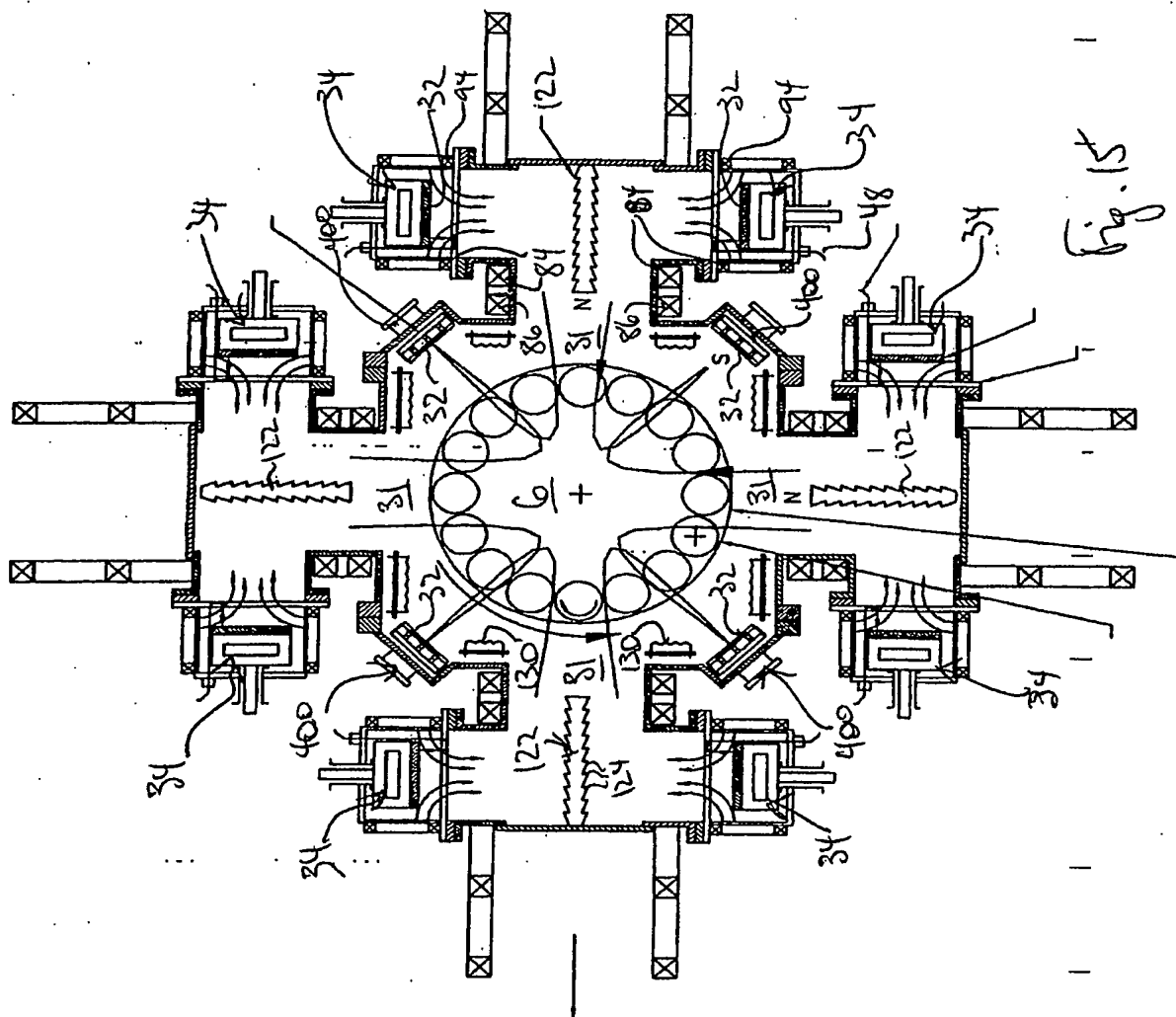
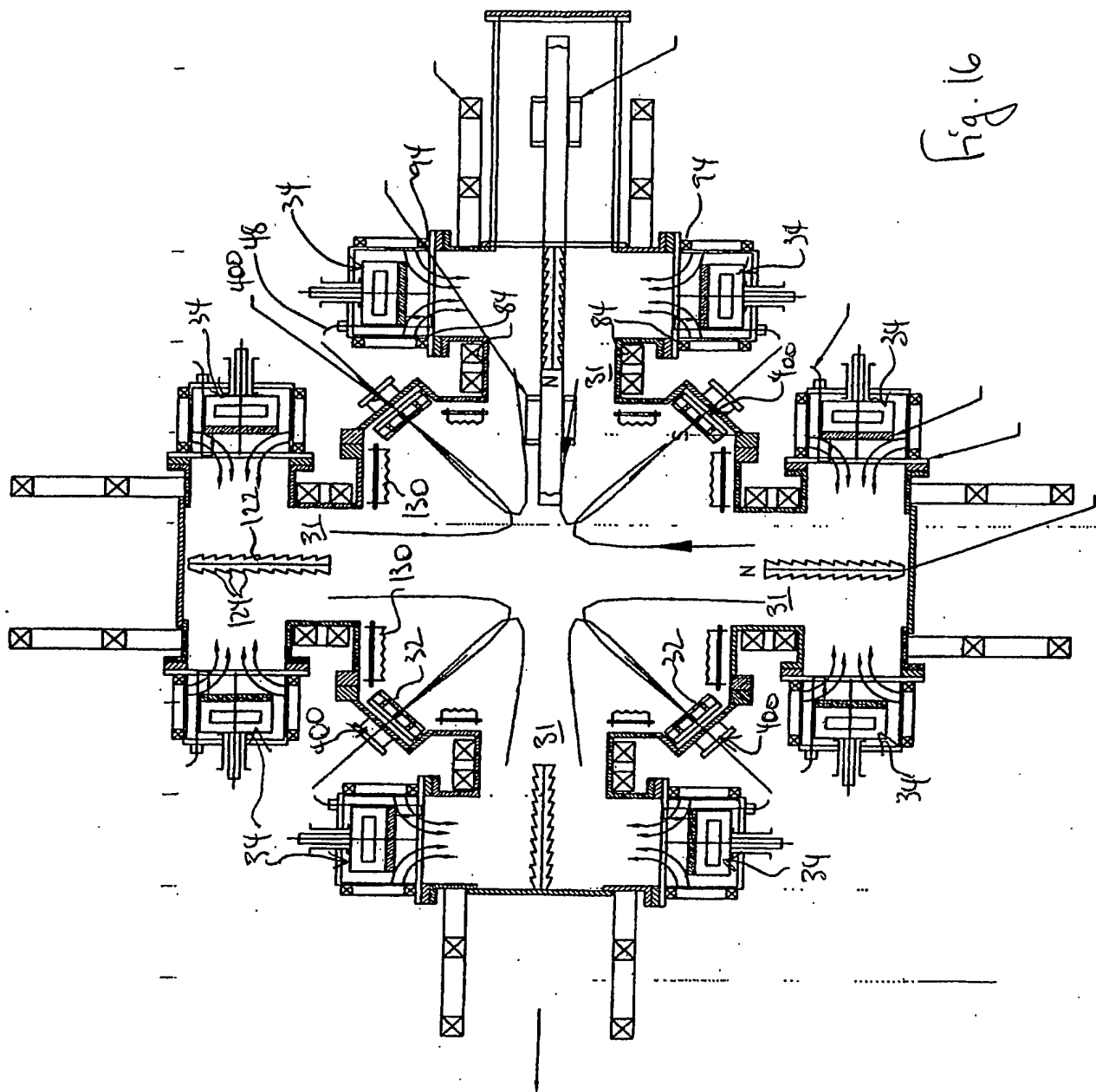


Fig. 15

WO 2005/040451

PCT/US2004/030603

25/26



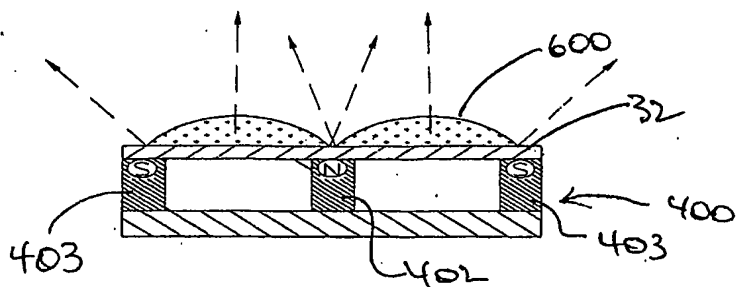


Fig. 17a

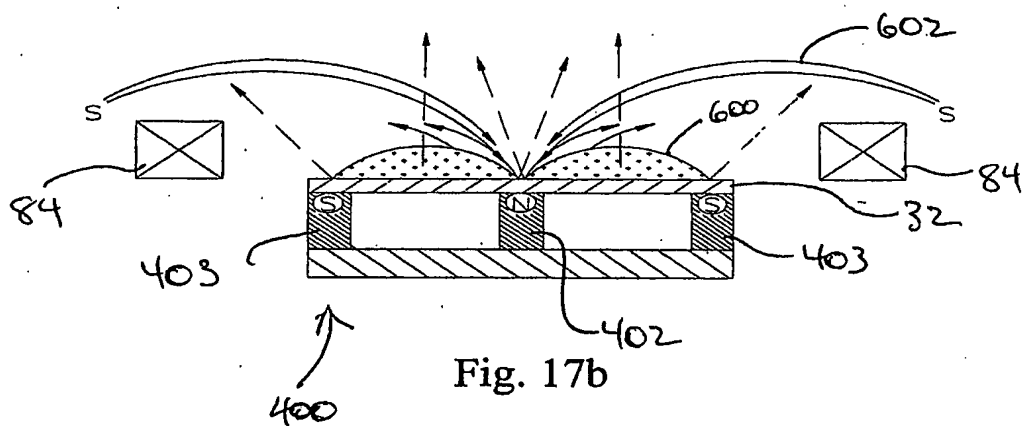


Fig. 17b

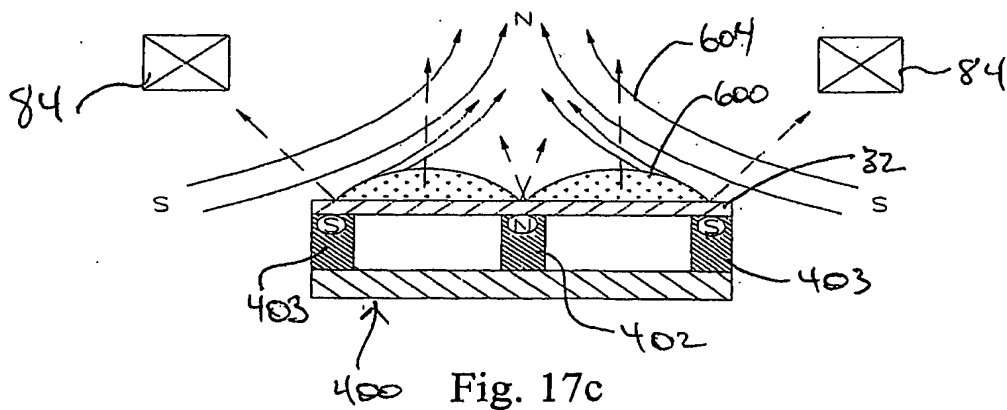


Fig. 17c

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US04/30603

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : C23C 14/32

US CL : 204/192.12, 192.38, 298.11, 298.14, 298.19, 298.2, 298.41

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 204/192.12, 192.38, 298.11, 298.14, 298.19, 298.2, 298.41

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,435,900 A (GOROKHOVSKY) 25 July 1995 (25.07.1995), Figure 1, 2A-2C, 3; Abstract; Column 3 lines 50-68; Column 4 lines 1-46.	1-44
A	US 5,380,421 A (GOROKHOVSKY) 10 January 1995, (10.01.1995), See Abstract; Figures 1-3.	1-44
A	US 5,298,136 A (RAMALINGAM) 29 May 1994 (29.05.1994), Abstract; Column 4 lines 3-14; Column 4 lines 24-30; Column 7 lines 45-68; Column 8 lines 1-2.	1-44
A	US 4,724,058 A (MORRISON, JR.) 09 February 1988 (09.02.1988), Abstract; Column 4 lines 10-16.	1-44

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

\* Special categories of cited documents:

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30 November 2004 (30.11.2004)

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